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ORIGINAL ARTICLE

Resistance to vertical root fracture of apicoected teeth using different devices during two root canal irrigation procedures

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Abstract

The aim of the present work was to measure the fracture resistance of endodontically treated teeth that were apicoected with different procedures. Seventy-two extracted human maxillary anterior teeth were included in this study. The specimens were randomly assigned to three main groups according to the apical surgery procedures and then two subgroups according to the irrigation protocols during root canal treatment and total of six groups were obtained ($n = 12$). Group 1: served as a control and apical surgery process was not performed in this group. Group 2: apical surgery process was performed with tungsten carbide fissure bur Group 3: apical surgery process was performed with Er:YAG laser. Subgroup a: In this group, the specimens were irrigated with %5 NaOCl. Subgroup b: 15% EDTA solution was filled into the root canal and then agitated using a 1.5 W/100 Hz diode laser. The specimens were filled and mounted in acrylic resin blocks and compression strength test was performed. Statistical analysis was performed using two-way ANOVA. The statistical analysis revealed that there were no statistical significant differences between apical surgery procedures (groups 1, 2, and 3) ($p < 0.05$). Apical resection procedures did not affect the fracture resistance Significant differences were determined between the subgroups ($p < 0.05$). Agitation of the EDTA with the diode laser reduced the fracture resistance of the specimens. The different canal irrigation techniques altered resistance to fracture; however, apical surgery procedures did not altered the resistance to fracture when compared with the control group.

Keywords Apicoectomy · Lasers · Er:YAG · EDTA

Introduction

The success of endodontic treatment depends on cleaning, shaping, disinfecting, and the hermetic obliteration of the root canal system and continuity of this process [1]. The main goal of biomechanical instrumentation is the elimination of the infected pulpal remnant debris and smear layer produced during the instrumentation of the root canal system [2]. Smear layer consists of organic and inorganic substances, including fragments of odontoblastic processes, microorganisms, and necrotic materials [3, 4]. Smear layer of the root canal is a product of mechanical instrumentation that avoids

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qualified penetration of irrigating solutions and intracanal medicaments into the dentinal tubules. Smear layer may also act as a barrier between root filling materials and dentin [5]. For effective irrigation, the canal irrigation solution should be in contact with the root canal walls [6]. The agitation of the irrigating solution could increase its efficacy for removing of the smear layer [7]. Laser devices and physical techniques have been suggested for the removal of the smear layer using chemical agents [8]. A diode laser has some benefits for clinical applications, which make it a precious device for endodontic treatments. This device has thin flexible fibers that can access all dimensions and curved shapes of the root canal system and increase the disinfection ability of the deep radicular dentin [9, 10]. In this sequence, it has been reported that agitation of ethylenediaminetetraacetic acid (EDTA) 20 s with a 808-nm diode laser improves the effectiveness of EDTA in removing the smear layer [11].

Endodontic treatment has a high rate of success; however, in some cases, endodontic surgery may be required [12]. The basic aim of periapical surgery is to form a barrier between the root canal and the periapical tissues. Due to the variations of the apical root anatomy, an apical resection is performed perpendicular to the long axis of the root, 3 mm from its tip, to eliminate the source of treatment failure. The retrograde cavity preparation is performed with parallel walls and a depth of 2.5–3 mm. Various techniques and instruments have been recommended for apicoectomies and the preparation of retrograde cavities [13]. Studies have reported that the Er:YAG (erbium-doped yttrium aluminum garnet laser, erbium YAG laser) laser is an appropriate device for resection and preparing cavities with sufficient water cooling without causing thermal damage to the surrounding tissues [14, 15]. Laser devices have some advantages over traditional methods (burs used with dental micro-handpieces). These advantages include disinfection of the surgical site, absence of vibration (resulting in increased patient comfort), and a reduction of exposed dentinal tubules, which may prevent the leakage of microorganisms and their products [16].

Endodontic treatments and periapical surgeries render the tooth more sensitive to susceptible [17]. The loss of dentin tissue either in the root canal or on the apical surface, dehydration of the dentin, pressure through the obturation procedures, and different irrigation protocols during these treatment processes have serious effects on root fractures [18–20]. Some studies have reported the effect of various apical surgery procedures on root dentin [21]. The resistance to root fracture of apicoected teeth has not yet been determined. The null hypothesis was that the fracture resistance of endodontically treated teeth would be reduced with both apical surgery procedures and diode laser irrigation procedures.

Materials and methods

Sample preparation

Seventy-two extracted human maxillary anterior teeth with completed apices and no resorption or calcification were included in this study. Teeth were extracted from patients ranging in age from 40 to 50 years. The teeth were stored in distilled water at 4 °C until they were used. To evaluate the anatomical structures of the specimens, buccolingual and mesiodistal radiographs were taken. Teeth with either cracks or a crack line were discarded after being viewed with a stereomicroscope (Novex, Arnhem, Holland) at × 20 magnification. Calculi and soft tissue remnants were removed with a periodontal scaler from the root surface. The teeth were sectioned with a diamond disk (Diamond Disc Superflex 910S/220, North Bel, Italy) under water coolant to standardize the root length at 14 mm. A size #10 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland) was moved down into the canal until the file was just visible. Endodontic working lengths were determined by reducing 1 mm from these lengths. Root canals were prepared with the ProTaper rotary system (Dentsply/Maillefer, Ballaigues, Switzerland) in the following sequence: SX, S1, S2, F1, F2, and F3. Root canals were irrigated with 2 ml of 5% NaOCl (Wizard, Rehber Kimya San. Tic. Aş. Istanbul, Turkey) between the files. All irrigation procedures were performed using 31-G/27 mm side-port irrigation needles (Navi Tip, Ultradent, South Jordan, UT, USA) at a distance 1 mm to the working length.

By tossing a coin, the selected specimens were randomly assigned by an author different from the operators to one of the following: a total of experimental six groups ($n = 12$ per group) (3 main groups and two subgroups). The specimens were mounted in a jig to simulate the periodontium. Group treatments are outlined below.

Group 1a In this group, the specimens were irrigated for 120 s with 5 ml of 5% NaOCl followed by a final rinse with 10 ml of distilled water. The total irrigation volume was 15 ml. After the irrigation procedures, the specimens were dried with paper points and filled with Endo Plus resin-based root canal sealer (President Dental, Duisburg, Germany) using the cold-lateral condensation technique. The specimens were immediately placed in conditions of 37 °C and 100% humidity for 1 week.

Group 1b In this group, 1 ml of 15% EDTA (Wizard, Rehber Kimya San. Tic. Aş., Istanbul, Turkey) solution was filled into the root canal and then agitated using a 1.5 W/100 Hz diode laser (Doctor Smile Erbium & Diode, Lambda Scientifica Srl, Vicenza, Italy). These parameters were used due to the positive results of the previous study [22]. The laser device was introduced into the root canal 1 mm from the working length. The 200-μm fiber tip was activated and withdrawn gently from the apical region to the coronal region with helical movements and then reintroduced at the apex. Agitation was performed for 10 s; then, irradiation was stopped for 15 s for a thermal rest. This procedure was repeated four times, giving a total agitation time of 40 s. After the agitation protocol, the specimens were irrigated for 80 s with 1 ml of 15% EDTA as a final flush, and irrigated with 5 ml of 5% NaOCl for 120 s followed by a final rinse with 5 ml of distilled water. The total irrigation volume was 15 ml. After the irrigation procedures, the specimens were dried with paper points and filled with Endo Plus resin-based root canal sealer using the cold-lateral condensation technique. The specimens were immediately placed in conditions of 37 °C and 100% humidity for 1 week.

These groups served as the controls and the apical surgery process was not performed in these groups.

Group 2a In this group, the irrigation protocol was performed as same as in the group 1a. After the irrigation procedures, the specimens were dried with paper points and filled with Endo Plus resin-based root canal sealer using the cold-lateral condensation technique. The specimens were immediately placed in conditions of 37 °C and 100% humidity for 1 week. The apical resection process was performed with tungsten carbide fissure burs (HM 31L 010 Meisinger, Neus, Germany) at an angle of 90° to the long axis of the root, and root-end cavities were prepared with tungsten carbide round burs (HM 1010 Meisinger, Neus, Germany) at a low speed with a 3.0-mm depth and 1.5-mm diameter. The depth of the root-end cavity was checked using a periodontal probe. The root-end cavities were rinsed with 2 ml of saline using a NaviTip needle (Ultradent Products Inc., South Jordan, UT, USA) attached to a syringe and dried with absorbent paper points. Mineral trioxide aggregate (MTA; Angelus, Londrina, PR, Brazil) was prepared according to the manufacturer's instructions. The root-end filling material MTA was inserted into the root-end cavity with an amalgam carrier, then condensed with appropriately sized condensers and burnished.

Group 2b The irrigation protocol was performed as same as in the group 1b. After the irrigation procedures, the specimens were dried with paper points and filled with Endo Plus resin-based root canal sealer using the cold-lateral condensation technique. The specimens were immediately placed in conditions of 37 °C and 100% humidity for 1 week. Apical surgery process was performed as same as group 2a.

Group 3a The irrigation protocol was performed as same as in the group 1a. After the irrigation procedures, the specimens were dried with paper points and filled with Endo Plus resin-based root canal sealer using the cold-lateral condensation technique. The specimens were immediately placed in conditions of 37 °C and 100% humidity for 1 week. The apical resection process was performed with an Er:YAG laser (AT Fidelis Fotona, Ljubljana, Slovenia) device at an angle of 90° to the long axis of the root. The Er: YAG laser was set to an energy of 300 mJ and a repetition rate of 25 Hz with R014 contact hand piece. Laser irradiation was performed at 300 μs (short pulse) pulse duration with sapphire tip diameter of 1.3- and 12-mm length, under cooling with a continuous air/water mist 14 ml/min in accordance with the manufacturer's instructions. The results of these parameters, energy density was set at 46.1 J/cm^2. Root-end cavities were prepared at 2.94 nm, 250 mj, and 15 Hz with cooling with a continuous air/water mist 1 ml/min. Cavity was prepared at 300 μs (short pulse) with sapphire tip diameter of 1- and 12-mm length. These parameters were used due to the positive results of the previous study [21]. Root-end resections and root-end cavities were prepared the same as group 2a.

Group 3b The irrigation protocol was performed as same as in the group 1b. After the irrigation procedures, the specimens were dried with paper points and filled with Endo Plus resin-based root canal sealer using the cold-lateral condensation technique. The specimens were immediately placed in conditions of 37 °C and 100% humidity for 1 week. Apical surgery process was performed as same as group 3a.

In preparation for the fracture test, the specimens were immersed into the melted boxing wax and taken out immediately in order to imitate the environmental tissues. The specimens were embedded along the long axis with 6 mm of each root exposed into the self-curing acrylic blocks. When the polymerization began, the specimens were removed, and the wax was removed using a periodontal scaler. The teeth were coated with a vinyl polysiloxane impression material, and the specimens were mounted vertically in acrylic resin (Imicryl, Konya, Turkey) by exposing 6 mm of the coronal part, and then maintained in 100% humidity for 1 week before mechanical testing to avoid dehydration of the specimens. The compression strength test was performed using a Universal Testing Machine (Instron Corp, Norwood, MA, USA) shown in Fig. 1. Compressive loading was applied vertically on the long axis of the specimens at a constant crosshead speed of 1 mm/min using a 4-mm diameter steel spherical tip until a fracture occurred. The force was recorded in Newtons when the fracture occurred. A Shapiro-Wilks statistical test for normality revealed a normal distribution, and the homogeneity of variances was assessed by Levene's test. The statistical analysis was then carried out using a two-way analysis of variance (ANOVA). All statistical analyses were performed using the SPSS software (SPSS, Inc., Chicago, IL, USA).

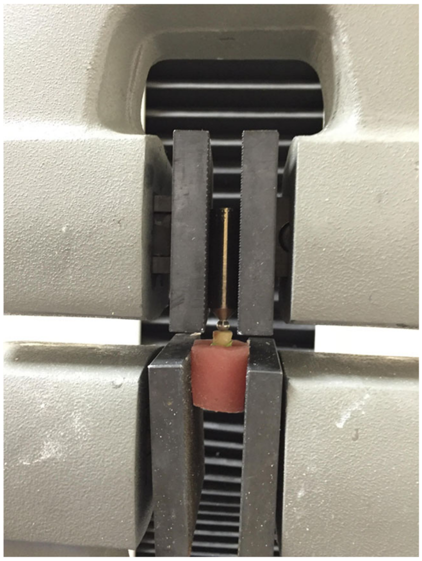

Fig. 1 Fracture test of the specimen

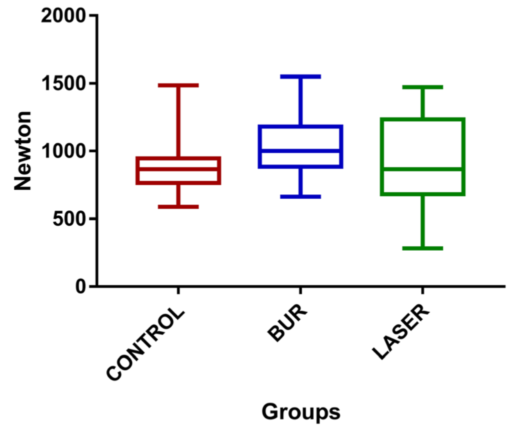

Fig. 2 Box-plot graphic of fracture resistance of apical resection procedures

Results

The mean max force values of the groups were as follows: 901,204 ± 51,861 N for control group, 1034,229 ± 51,861 N for tungsten carbid bur group, and 930,963 ± 51,861 for Er:YAG laser group. There was no statistically significant difference between the main groups (groups 1, 2, and 3) ($p < 0.05$) shown in Fig. 2. Apical resection procedures did not affect the fracture resistance. However, there was a significant difference between the subgroups (group NaOCl and group EDTA) ($p < 0.05$). The mean max force values of the subgroups were as follows: 1031,428 ± 42,344 N for NaOCl subgroup and 879,503 ± 42,344 N for EDTA subgroup (Table 1). Agitation of the EDTA with the diode laser reduced the fracture resistance of the specimens. All groups' results are summarized in Table 2.Generally, apical resection with the tungsten carbide bur had higher fracture resistance values compared with the laser group, but this difference was not statistically significant. If we handle the NaOCl groups and EDTA groups separately, there is no significant difference between the fracture resistance of the specimens (Table 3).

Discussion

In the present study, two different apical surgery processes did not affect the fracture resistance of the specimens but irrigation protocol that performed with agitation of EDTA decrease the fracture resistance. Agitating the EDTA with a diode laser to remove the smear layer is typically used in endodontic treatments. A previous study evaluated the smear layer removal with agitated EDTA using a diode laser. They reported that the agitation of EDTA with a diode laser (10, 20, 30, and 40 s) resulted more open dentinal tubules (total exposure time: 120 s) compared to the control group [11]. In this study, the exposure time to the 15% EDTA was standardized at 120 s, and the chosen agitation time was 40 s to remove the smear layer. The diode laser parameters of 1.5 W/100 Hz were chosen according to another previous study that had evaluated the temperature variation on the root's external walls using a diode laser [23]. They found that 1.5 and 3 W parameters could be safely used in endodontic treatment.

Faria et al. [24] evaluated the effectiveness of a 980-nm diode laser (1.5, 3 W) on the fracture resistance of teeth. They found that the laser treatment did not alter the fracture resistance of the root. Karataş et al. [22] reported that a 3 W/100 Hz single diode laser application and the agitation of EDTA with a 1.5 W/100 Hz diode laser did not affect fracture resistance, and agitation of EDTA with a 3 W/100 Hz diode laser for both 20 and 40 s decreased the fracture resistance of teeth. In the present study, if only subgroups were considered, EDTA agitation with a 1.5 W/100 Hz diode laser decreased the fracture resistance compared to NaOCI; however, there was no significant difference between the groups. Thus, there was a positive correlation between fracture resistance and the loss of tooth structures.

There are previous studies in the literature concerning the fracture resistance of teeth that have had a root canal treatment, but less is known about the effect of apical resection procedures on fracture resistance and also there is any study in the literature that involves Er:YAG and diode laser together used in root canal treatment for assessing the fracture resistance. Therefore, in the present study, two different apical resection procedures were performed after a root canal treatment was applied with irrigation activation methods with a diode laser. The aim was to observe the fracture resistance of apicoected teeth using different devices.

Erbium group lasers have been used in apical resections and root preparations to provide apical sealing [25]. Although the apical resection procedure took a longer time with the laser, there are some benefits including less

Table 1 Mean and standard deviation of fracture resistance of NaOCl and EDTA groups

Subgroups	Mean	Std. error	Lower bound	Upper bound
NaOCl	1031,428	42,344	946,885	1115,971
EDTA (diode laser agitation)	879,503	42,344	794,960	964,046

vulnerability, no cracks or fewer cracks, removal of the smear layer, less discomfort due to adjacent tissues, less vibration, and less trauma [26–30]. Lasers have also been shown to reduce apical dentinal permeability. Removal of the smear layer allows retrograde filling lengthen into the opened dentinal tubules [31]. In the present study, we preferred to use the Er:YAG laser due to these superior advantages.

In the literature, there have been no investigations concerning fracture resistance comparisons of apical resection devices. To conduct the present study, we consulted the results of previous studies that compared different root-end preparation procedures. Aydemir et al. [21] evaluated the root surfaces and the number of cracks after resection and root-end cavities with Er:YAG laser and tungsten carbide burs and reported no significant difference in crack number or type between the conventional and laser groups. Due to the results of this study we use the same Er:YAG laser parameters (300 mj, and 25 Hz for resection and 250 mj, and 15 Hz for root-end cavity preparation). Angiero et al. [32] evaluated the efficacy of erbium lasers for retrograde endodontic treatment in terms of clinical outcomes. They reported that all episodes of endodontic surgery may be performed with erbium lasers. Ayranci et al. [33] evaluated root surfaces and crack numbers using an Er:YAG laser, carbide burs, and diamond-coated ultrasonic tips. They reported that the Er: YAG laser produced a rougher resected root surface than the carbide burs; however, the diamond-coated tip provoked many dentinal crack formations compared to the Er:YAG laser and tungsten carbide bur. The present study evaluated fracture resistance of root-end cavity preparation using tungsten carbide burs and an Er:YAG laser, and there was no significant difference between preparation techniques. Therefore, it can be suggested that fracture resistance and crack formation in resected roots were related to each other, but further studies are needed to confirm this correlation.

Table 2 Descriptive statistics of groups

Groups		Mean	Std. deviation	*N*
Control	NaOCl	943,567	291,3623	12
	EDTA + diode laser activation	858,842	125,7645	12
	Total	901,204	223,6909	24
Bur	NaOCl	1112,017	257,5996	12
	EDTA + diode laser activation	956,442	151,0235	12
	Total	1034,229	221,2655	24
Laser	NaOCl	1038,700	304,1403	12
	EDTA + diode laser activation	823,225	323,9145	12
	Total	930,963	326,3912	24
Total	NaOCl	1031,428	285,4802	36
	EDTA + diode laser activation	879,503	219,9457	36
	Total	955,465	264,3378	72

In this study, we reported that there is no significant difference between the six groups. If we handle the NaOCl groups and EDTA groups separately, there is no significant difference between the fracture resistance of the specimens. However, the bur group fracture resistance values were higher than the other groups in both EDTA and NaOCl groups. There is no study to compare these results. Therefore further studies are needed.

Gangliani et al. [34] compared root-end resections at 45° and 90° angles from the long axis of the root. They reported that, as the root-end bevel increased, the opened dentinal tubules on the resected root surfaces were increased. This long bevel also resulted in the inadequate removal of the tooth structure. The extent of the apical root resection is based on the findings that removing 3 mm of apical root end reduces apical ramifications and lateral canals. Therefore, in the present study, root-end cavity preparation was completed at a 90° angle and a 3-mm depth.

Linsuwanont et al. [35] evaluated the resistance of simulated human immature teeth that performed mineral trioxide aggregate (MTA) apexification and have been root-filled with fiber post, composite resin, MTA, or gutta-percha, to vertical root fracture. They reported that fracture resistance of the simulated immature tooth group was significantly lower than in the intact tooth, MTA, fiber post, and composite resin groups; however, it was not significantly different from the gutta-percha group. This study showed that the fracture resistance of gutta-percha + MTA group was lower than intact teeth. Therefore, decrease in root canal dentin thickness reduces the fracture resistance. However, according to our present study, decrease in apical dentin did not alter the fracture resistance of teeth that were strengthen with calcium silicate-based cement MTA.

Table 3 One-way analysis of NaOCI and EDTA subgroups according to the apical surgery procedure

Groups		*N*	Mean	Std. deviation	*p*
NaOCl	Control	12	943,5667	291,36228	.360
	Bur	12	1112,0167	257,59956	
	Laser	12	1038,7000	304,14026	
EDTA	Control	12	858,8417	125,76449	.316
	Bur	12	956,4417	151,02348	
	Laser	12	823,2250	323,91447	

Another previous study reported results regarding the ability of MTA to strengthen the tooth structure [36]. Bortoluzzi et al. [37] stated that MTA enhances the resistance to horizontal root fracture when used as an obturation material for immature teeth. In the present study, the agitation of EDTA with a diode laser reduced the fracture resistance of the specimens compared with NaOCI, but in general, if we handle six groups, EDTA subgroups did not alter the fracture resistance. This result may be associated with the strengthened tooth structure with MTA. Aksel et al. [38] reported that MTA increased fracture resistance of simulated immature permanent teeth. Present study was in accordance with the previous study. White et al. [39] reported that MTA reduces the fracture resistance of bovine dentin by 33%. When MTA was used for hermetic apical seals, the important condition was the MTA's thickness. Cicek et al. [36] reported that complete obturation of the root canal with MTA may cause a tendency to fracture. Therefore, MTA may be safely used for performing an apical barrier between 3- and 6-mm thick in immature teeth. For this reason, a 3-mm MTA thickness was chosen as a root-end filling material in this study.

Conclusion

The null hypothesis was partially rejected by the results of present study. Irrigation protocol that performed with diode laser decreases the fracture resistance of the specimens. Within the limitations of this study, it can be concluded that resection and root-end preparation methods did not affect the fracture resistance of teeth, notwithstanding the methods. Further studies are needed to evaluate the apical resection procedures.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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