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Evaluation of the Effect of Different Irrigation Systems on the Removal of Intracanal Medicaments

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ABSTRACT

Objectives: This study aimed to evaluate the effects of different irrigation systems on the removal of intracanal medicament used in regenerative endodontic treatment.
Materials and Methods: Following standardized preparation to obtain an immature tooth model, modified triple antibiotic paste (mTAP) consisting of metronidazole, ciprofloxacin and clindamycin was applied to the root canals of single-rooted human maxillar teeth and waited for three weeks. A total of 50 teeth with standardized preparation and intracanal medicament were randomly divided into five groups according to the irrigation method to be applied (n=10); Group 1: Conventional Syringe Irrigation (CSI), Group 2: Passive Ultrasonic Irrigation (PUI), Group 3: EndoActivator (EA), Group 4: EndoVac (EV) Group 5: Nd:YAG laser (LSR). Following the removal of the mTAP with different irrigation systems, the teeth were divided along their bukko-lingual axis. The impact roots were examined under the stereomicroscope with the 4-grade scoring scale for the presence of residual intracanal medicaments. Scores for coronal, middle and apical regions of each root were recorded.
Results: In terms of total scores, PUI group showed higher intracanal medicament removal efficacy compared to the other groups ($p<0.05$). In the intra-group comparison of the root canal third, less intracanal medicament was found in the apical third ($p <0.05$). The highest intracanal medicament removal efficacy was found in PUI and LSR groups in the coronal third, PUI group in the middle third, and PUI and EV groups in the apical third ($p<0.05$).
Conclusions: Intracanal medicament removal scores were significantly associated with irrigation system. PUI showed statistically significantly higher intracanal medicament removal efficiency than other irrigation methods. While there was no difference between the coronal and middle thirds, statistically significantly less intracanal medicament removal was found in the apical third compared to the other regions.

Keywords: Bond strength, biodentine, irrigation, intracanal medicament, regenerative endodontic treatment.

Farklı İrrigasyon Sistemlerinin Kanal İçi İlaçların Uzaklaştırılmasına Etkisinin İncelenmesi

Süreç

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ÖZ

Amaç: Bu çalışmanın amacı farklı irrigasyon sistemlerinin rejeneratif endodonti tedavisinde kullanılan kanal içi ilaçların uzaklaştırılması üzerindeki etkilerini değerlendirmektir.
Gereç ve Yöntem: İmmatür diş modeli elde etmek için standardize edilmiş preparasyonun ardından, tek köklü üst insan dişlerinin kök kanallarına metronidazol, siprofloksasin ve klindamisinden oluşan modifiye üçlü antibiyotik pat (mTAP) uygulanmış ve üç hafta beklendi. Standart preparasyon ve kanal içi ilaç uygulanan toplam 50 diş, uygulanacak irrigasyon yöntemine göre (n=10) rastgele beş gruba ayrıldı; Grup 1: Gelenekel Şırınga İrrigasyonu (GSI), Grup 2: Pasif Ultrasonik İrrigasyon (PUI), Grup 3: EndoActivator (EA), Grup 4: EndoVac (EV) Grup 5: Nd:YAG lazer (LZR). Farklı irrigasyon sistemleri ile mTAP'ın uzaklaştırılmasını takiben dişler bukko-lingual ekseni boyunca ayrıldı. Darbe kökleri, artık intrakanal ilaç varlığı için 4 dereceli puanlama skalası ile stereomikroskop altında incelendi. Her kökün koronal, orta ve apikal bölgeleri için skorlar kaydedildi.
Bulgular: Toplam puanlar açısından, PUI grubu diğer gruplara göre daha yüksek kanal içi ilaç uzaklaştırma etkinliği gösterdi ($p<0.05$). Kök kanal üçlüsünün grup içi karşılaştırmasında, apikal üçlüde daha az kanal içi ilaç bulundu ($p<0.05$). En yüksek kanal içi ilaç uzaklaştırma etkinliği PUI ve LZR gruplarında koronal üçlüde, PUI grubunda orta üçlüde ve PUI ve EV gruplarında apikal üçlüde bulundu ($p<0,05$).
Sonuçlar: Kanal içi ilaç uzaklaştırma skorları, irrigasyon sistemi ile istatistiksel olarak anlamlı şekilde ilişkiliydi. PUI, diğer irrigasyon yöntemlerine göre istatistiksel olarak anlamlı derecede daha yüksek kanal içi ilaç uzaklaştırma etkinliği gösterdi. Koronal ve orta üçlü arasında fark yokken, apikal üçlüde diğer bölgelere göre istatistiksel olarak anlamlı derecede daha az kanal içi ilaç uzaklaştırma saptandı.

Anahtar kelimeler: Bağlanma dayanımı, Biodentine, irrigasyon, kanal içi ilaç, rejeneratif endodontik tedavi.

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Introduction

The pulp of immature permanent teeth is at risk for necrosis due to trauma, dental anomalies or caries. Although apexification procedures were routinely used to treat apical periodontitis in immature necrotic young permanent teeth[1], they cannot provide ongoing root development as in the regenerative endodontic treatment (RET) procedure.[2]

RET is defined as biological applications that replace damaged tissues, including dentin and root structure, in addition to the cells in the pulp-dentin complex.[3] The advantage of RET over other existing treatment options is leading to increase in root length and the thickness of the root canal walls.[4] The basis of RET is the effective disinfection of the root canal. Calcium hydroxide (Ca(OH)2) and antibiotic pastes are often preferred for disinfection. However, antibiotic pastes have negative effects on the bond strength of calcium silicate-based cements.[5] Bond strength and marginal adaptation of endodontic material to dentin to prevent apical or coronal leakage is an important factor for the successful implementation of various endodontic treatment procedures.[6] Triple antibiotic paste (TAP) is acidic and, if not completely removed from the root canal, will cause insufficient bonding of calcium silicate cement to root dentin.[7]

Intracanal medicaments used in RET cannot be completely removed from the root canal with current irrigation methods and solutions.[5, 8-10] A wide variety of techniques and irrigation solutions have been used to remove antibiotic paste from mature permanent tooth root canals.[11, 12] However, there has been limited research attention on the removal of triple antibiotic paste from the root canal of immature teeth with different irrigation systems.

Calcium silicate-based cements are used as pulp barrier in RET to provide coronal sealing and to create resistance against incoming forces.[13, 14] In order to increase the bond strength of cements to dentin, intracanal medicaments must be removed from the root canal. [15-18] Therefore, evaluating the effects of irrigation methods on the bond strength of calcium silicate-based cements to dentin is important for clinical success in RET.

The aim of this study was to examine the effects of different irrigation systems on the removal of the mTAP used as intracanal medicament in RET. The null hypothesis was that here is no effect of irrigation system on intracanal medicament removal efficiency.

Materials and Methods

Ethics approval was obtained from the ethics committee with the decision dated 27.12.2016 and numbered 2016-12/08 from the Clinical Research and Ethics Committee of Sivas Cumhuriyet University. 50 single-rooted maxillary permanent incisors extracted for caries or orthodontically etc. reasons were examined under a stereomicroscope and with multi-angle preoperative radiographs (65 kVp, 8 mA, 0.1 sec, Novelix, Trophy). The inclusion criteria for the study were determined as follows; (a) single root and canal, (b) no previous root canal treatment, (c) canal angle less than 20 degrees. The exclusion criteria for teeth were determined as follows; (a) presence of caries, fractures, cracks, internal and external resorption on the root surface, (b) canal angle greater than 20 degrees, (c) extensive coronal destruction, and (d) calcification and obliteration of root canals.

In order to obtain a standard working size, the crowns of 50 single-rooted teeth were cut from the enamel-cementum junction with a steel separator with a root length of 15±1 mm. The mechanical root canal preparation was applied with TF Adaptive (SybronEndo, Glendora, CA, USA) rotary system files, ML1-ML2, respectively, and finished apically in ML3 (050.04 taper) size. Root canals were washed with 2 ml of 2.5% NaOCl at each rotary file change. In order to provide a standard 1.5 mm in-canal diameter and an immature tooth model, 1 mm protrusion from the apical was studied with Peezo reamers, starting from 1 and using reamer number 6 last, and a standard root canal diameter was achieved. The prepared teeth were irrigated with 5 ml of 2.5% NaOCl and then with 5 ml of 17% EDTA (Canal + Septodont, France). Final irrigation was performed with 10 ml of distilled water to remove the effects of the irrigation solutions used in the canal. Root canals were dried with sterile paper cones (Aceonedent, Geonggi-Do, Korea).

Modified triple antibiotic paste (mTAP, Metronidazole +Ciprofloxacin+Clindamycin) was prepared in accordance with the described procedure by Hoshino et al.[19] The procedure for intracanal medicament preparation was as follows; the coatings of Nidazole 500 mg film tablet (İ. E. Ulagay, Istanbul, Turkey) and Cipronatin 250 mg film tablet (Atabay, Istanbul, Turkey) were scraped with a surgical scalpel. Each antibiotic tablet was crushed separately in sterile porcelain mortars until powdery form. The powdered antibiotics were mixed on a clean glass at a ratio of 1:1. Then, 150 mg of Clindane capsules (Bilim, Istanbul, Turkey) were added to the resulting mixture, mixed homogeneously and a mixture was obtained at a ratio of 1:1:1. A homogeneous carrier was obtained by mixing macrol and propylene glycol at a ratio of 1:1 on a separate clean glass surface. Then, modified triple antibiotic paste (mTAP) was obtained by mixing 1 scoop of carrier and 5 scoops of antibiotic powder.

The prepared mTAP and distilled water were mixed with an antibiotic paste/sterile water ratio of 0.9 gr/ml. The paste was inserted to the root canals with a #40 lentulo file. Following placing cotton in the canals of 100 teeth, the teeth were closed with temporary filling material (Cavit; 3M ESPE, Seefeld, Germany). All samples were kept in an oven at 37ºC in a 100% humidity environment for 3 weeks.

A total of 50 teeth with standardized preparation and intracanal medicament were randomly divided into five main groups according to the test method to be applied (n=10 per each group): Group 1: Conventional Syringe Irrigation (CSI), Group 2: Passive Ultrasonic Irrigation (PUI), Group 3: EndoActivator (EA), Group 4: EndoVac (EV), Group 5: Nd:YAG Laser (LSR).

Standardized irrigation protocol was applied in all experimental groups. Intracanal medicament removal was performed on the teeth of each experimental group with the relevant irrigation method. 2.5% NaOCl, 17% EDTA and distilled water were used as irrigation solution. The irrigation solution flow rate and irrigation time were determined to be 5 ml/min.

Group 1: Conventional Syringe Irrigation (CSI)

An area where the 27 gauge injector cannula could advance was created by advancing from the coronal to the apical direction with the #30 K file by 1 mm shorter than the working length. The injector cannula was positioned 1 mm coronal from the working length and irrigated with 5 ml of 2.5% NaOCl for 1 minute, then 5 ml of 17% EDTA (Nazar Kimya Ltd., Istanbul) was applied to the canal for 1 minute. Finally, the canals were irrigated with 10 ml of distilled water.

Group 2: Passive Ultrasonic Irrigation (PUI)

An area where the ultrasonic tip can be placed was created by advancing from the coronal to the apical direction with the #30 K file by 1 mm shorter than the working length. The irrigation tip of the VDW ULTRA ultrasonic device (VDW, Munich, Germany) was positioned 1 mm shorter than the working length with an application power of 25 (irrigation mode) in accordance with the manufacturer's instructions. Irrigation was performed in three rounds of twenty seconds each. After the root canal was filled with 2.5% NaOCl, the tip of the ultrasonic device was activated for 10 seconds, 2 mm up-down movement was made, and then the irrigation solution was renewed for 10 seconds and waited. In this way, a total of 3 rounds of irrigation were performed. Then, irrigation was done in a similar way for 1 min with 5 ml of 17% EDTA. Finally, the canals were irrigated with 10 ml of distilled water.

Group 3: EndoActivator (EA)

An area where the polymer tip can be placed was created by advancing from the coronal to the apical direction with the #30 K file in the root canal by 1 mm shorter than the working length. The power of the EndoActivator (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) sonic irrigation device was adjusted to 10000 cpm by attaching the irrigation tip number 25 and positioning it 2 mm shorter than the working length. Irrigation was performed in three rounds of twenty seconds each. After the root canal was filled with 2.5% NaOCl, activation was performed with 3 mm slight back and forth movements for 10 seconds, and then the irrigation solution was renewed for 10 seconds and waited. In this way, a total of 3 rounds of irrigation were performed. Then, irrigation was done in a similar way for 1 min with 5 ml of 17% EDTA. Finally, the canals were irrigated with 10 ml of distilled water.

Group 4: EndoVac

Final irrigation procedure was performed according to the manufacturer's instructions. After active irrigation with 2.5% NaOCI for 30 seconds with the macrocannula, the canals were filled with NaOCI and a total of 30 seconds of irrigation was performed with the microcannula in 6 seconds working size, 2 mm shorter than 6 seconds working size, and 6 seconds working size, respectively. Then, after 30 seconds of active irrigation with 17% EDTA, the root canals were filled with EDTA and a total of 30 seconds of EDTA irrigation was performed with a microcannula in 6 seconds working size, 2 mm shorter than 6 seconds working size, and 6 seconds working size, respectively. Finally, the canals were irrigated with 10 ml of distilled water.

Group 5: Nd: YAG Laser (LSR)

An area where the laser tip can be placed was created by advancing from the coronal to the apical direction with the #30 K file by 1 mm shorter than the working length. Nd:YAG (Fidelis, Fotona, Ljubljana-Slovenia) laser with a wavelength of 1064 nm adjusted to 1.5 W energy, 100 mJ pulse rate and 15 Hz frequency as recommended[20], was placed in the 200 µm fiber optic end channel attached to the laser. Irrigation was performed in three rounds of twenty seconds each. After the root canal was filled with 2.5% NaOCl, activation was performed with an optical fiber tip for 10 seconds, and the irrigation solution was renewed for 10 seconds and waited. During the irrigation activation, the optic tip was applied by moving it from the apical foramen to the canal mouth with uninterrupted circular movements. Then, irrigation was performed in a similar way for 1 min with 5 ml of 17% EDTA. Finally, the canals were irrigated with 10 ml of distilled water.

The root canals of a total of 50 teeth with standardized irrigation protocol for each irrigation method group were dried with sterile paper cones (Aceonedent, Geonggi-Do, Korea) by advancing to the working length.

Grooves of sufficient depth were created on the mesial and distal surfaces of the roots along the long axis, taking care not to penetrate the root canals with a diamond cutting separator. Afterwards, the roots were divided into two with the help of a strong and sharp hand tool. The intact part of the roots obtained along the long axis was selected for stereomicroscopic evaluation in terms of the amount of residual intracanal antibiotic paste.

Stereomicroscopic Analysis

A stereomicroscope (Zeiss, Oberkochen, Germany) was used to examine the coronal, middle and apical third regions of the prepared root canal walls for residual intracanal medicament presence. All samples were examined under 25X magnification with a stereomicroscope and images were recorded with a camera (Canon EOS 1000D, Japan) connected to the stereomicroscope.

A 4-point scoring scale defined by Van der Sluis *et al.*[21] was used for evaluation.

- Score 0: The root canal is completely clean, there is no residual medicament in the canal.
- Score 1: Less than 50% of the root canal has residual intracanal medicament.
- Score 2: More than 50% of the root canal has residual intracanal medicament.
- Score 3: There is residual intracanal medicament in almost the entire root canal.

Scoring of the images was performed by two researchers (B.B and C.H). Each researcher evaluated each image twice, three weeks apart, independently of each other, on different dates and without knowing which group the samples belonged to. In the final scoring, both researchers examined the images with disagreement together and reached a final consensus.

Statistical Evaluation

The data were analyzed using the SPSS (Version 22.0; SPSS Inc., Chicago, USA) program. Kappa statistics were used for the intra-observer and inter-observer agreement. Parametric test assumptions were tested with Kolmogorov-Smirnov test. Kruskal-Wallis and Mann-Whitney U tests were used for pairwise comparisons in case of significance, since parametric test assumptions were not fulfilled. Descriptive statistics including mean, standard deviation, median, minimum and maximum values were presented in the tables. The significance level was set at 0.05.

Results

The distribution of intra-canal medicament removal scores of the experimental groups and the comparison of the root regions in terms of the intra-group comparisons are shown in Table 1 and Figure 1. The findings showed that the different irrigation systems had a statistically significant effect on intracanal medicament removal ($p<0.05$).

With regard to irrigation methods, the intracanal medicament removal scores of the PUI group were found to be statistically significantly lower than the scores of the LSR, EV, EA and CSI groups ($p<0.05$). Although there was no statistically significant difference between the LSR and EV groups ($p>0.05$), the scores of the two groups were found to be statistically significantly lower than the scores of the EA group ($p<0.05$). The scores of the EA group were statistically significantly lower than the CSI group ($p<0.05$). The scores of the CSI group were statistically significantly higher than the scores of the PUI, LSR, EV and EA groups ($p<0.05$).

With regard to root regions, although there was no statistically significant difference between the intracanal medicament removal scores of the coronal and middle third ($p>0.05$), the scores of these two groups were found to be statistically significantly lower than the scores of the apical third. The intracanal medicament removal scores of the apical third were statistically significantly higher than the scores of the coronal and middle third.

There was no statistically significant difference between the scores of the coronal, middle and apical third of the PUI group ($p>0.05$). In the EA group, although there was no statistically significant difference between the coronal and middle third ($p>0.05$), higher intracanal medicament was removed with statistically significantly lower scores than the apical third region ($p<0.05$). No statistically significant difference was found between the scores in the coronal, middle and apical thirds in the EV group ($p>0.05$). In the LSR group, although the scores of the coronal triplet region were statistically significantly lower than the middle and apical third regions ($p <0.05$), no statistically significant difference was found between the middle and apical third ($p>0.05$). There was no statistically significant difference between the scores of the coronal, middle and apical third regions in the CSI group ($p>0.05$).

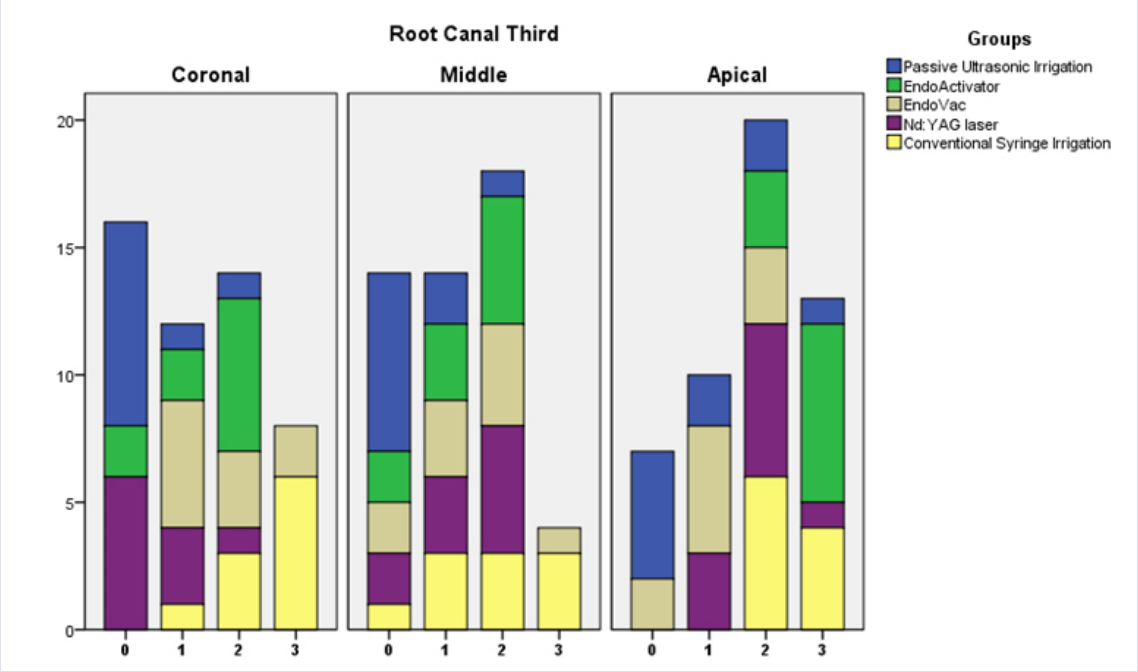

Figure 1. *Distribution of intracanal medicament removal scores of the experimental groups according to root regions*

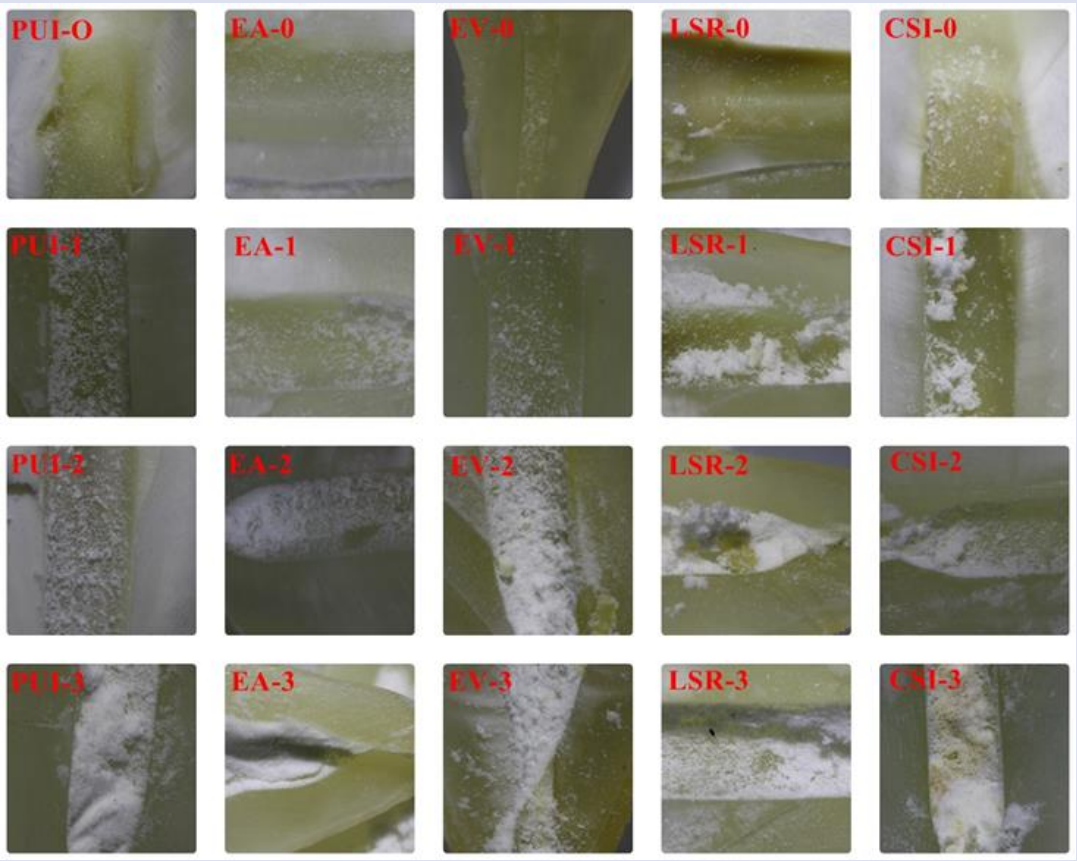

Figure 2. *Representative intracanal residual medicament presence and scores of the sections taken from the samples belonging to each experimental group*

Table 1. Intra-group comparison of the distribution of intracanal medicament removal scores of the experimental groups and root regions.

Scores	0	1	2	3	Median	Root region*
Passive Ultrasonic Irrigation						*p*>0.05
Coronal	8	1	1	-	0.0	
Middle	7	2	1	-	0.0	
Apical	5	2	2	1	0.5	
EndoActivator						
Coronal	2	2	6	-	2.0	A
Middle	2	3	5	-	1.5	A
Apical	-	-	3	7	3.0	B
EndoVac						*p*>0.05
Coronal	-	5	3	2	1.5	
Middle	2	3	4	1	1.5	
Apical	2	5	3	-	1.0	
Nd:YAG Laser						
Coronal	6	3	1	-	0.0	A
Middle	2	3	5	-	1.5	B
Apical	-	3	6	1	2.0	B
Conventional Syringe Irrigation						*p*>0.05
Coronal	-	1	3	6	3.0	
Middle	1	3	3	3	2.0	
Apical	-	-	6	4	2.0	

*Comparisons were performed within the group in terms of root regions of each group (Kruskal-Wallis and Mann-Whitney U tests. p<0.05). Different letters represent statistically significant difference.

Table 2. Pairwise comparisons and p values of the experimental groups in terms of each root region

Root Region	Groups	1	2	3	4	5
Coronal						
	1. Passive Ultrasonic Irrigation	-	**.008**	**.001**	.399	**.000**
	2. EndoActivator		-	.626	**.024**	**.006**
	3. EndoVac			-	**.004**	**.037**
	4. Nd:YAG Laser				-	**.000**
	5. Conventional Syringe Irrigation					-
Middle						
	1. Passive Ultrasonic Irrigation	-	**.021**	**.019**	**.021**	**.004**
	2. EndoActivator		-	.840	1.000	.266
	3. EndoVac			-	.840	.386
	4. Nd:YAG Laser				-	.266
	5. Conventional Syringe Irrigation					-
Apical						
	1. Passive Ultrasonic Irrigation	-	**.001**	.473	**.043**	**.004**
	2. EndoActivator		-	**.000**	**.005**	.189
	3. EndoVac			-	**.044**	**.001**
	4. Nd:YAG Laser				-	**.038**
	5. Conventional Syringe Irrigation					-

* Bold values represent statistically significant difference (Kruskal-Wallis and Mann-Whitney U tests. p<0.05).

The p-values of pairwise comparisons between groups in terms of each root third and irrigation method are shown in Table 2. There were significant differences between the groups in terms of root regions of the tested irrigation systems (p<0.05). Although there was no statistically significant difference between the PUI and LSR groups in the coronal third (p>0.05), the scores of the two groups were found to be statistically significantly lower than the scores of the EV, EA and CSI groups (p<0.05). Although there was no statistically significant difference between the EV and EA groups in the coronal third (p>0.05), the scores of the two groups were found to be statistically significantly lower than the scores of the CSI group (p<0.05). The CSI group, on the other hand, showed lower intracanal medicament removal efficiency with a statistically significant difference with all groups (p<0.05).

In the middle third, the scores of the PUI group were found to be statistically significantly lower than the scores of the LSR, EV, EA and CSI groups (p<0.05). Although there was no statistically significant difference between the LSR, EV, EA and CSI groups (p>0.05), they showed the lowest intra-canal medicament removal efficiency, with a statistically significant difference (p<0.05).

Although there was no statistically significant difference between the PUI and EV groups in the apical third (p>0.05), the scores of the two groups were found to be statistically significantly lower than the scores of the LCR, EA and CSI groups (p<0.05). LSR group scores were statistically significantly lower than EA and CSI groups (p<0.05). Although there was no statistically significant difference between the EA and CSI groups (p>0.05), it showed lower intracanal medicament removal efficiency with a statistically significant difference with all groups (p<0.05).

Discussion

The first null hypothesis was rejected because different irrigation systems had a statistically significant effect on intracanal medicament removal. The second null hypothesis was rejected because there was statistically significant difference between root canal third on intracanal medicament removal scores. Findings of this study showed that irrigation system had effect both on intracanal medicament removal. As intracanal medicaments used in RET reduce the bond strength of materials to root canal dentin, they should be removed from root canals. Residual intracanal medicaments also cause tooth discoloration and damage the stem cells in the apical papilla.[22]

This study was conducted with extracted human permanent tooth was used for our study. In in vitro studies, for the standardization of imitated immature tooth samples, the root tips of the teeth to be used in the studies were required to be closed, single rooted and single canal. Teeth that did not have these characteristics were not used in this study. It has been sought that there should not be any caries, crown or root fracture, crack or root resorption in the teeth that could change the results of the study.

Different methods have been used in different studies in order to provide the apical form of the immature tooth.[5,23,24] Topcuoglu *et al.*[24] studied 1 mm protrusion from the apex with a #6 no Peeso reamer. Based on the methodology of these studies, the immature tooth model was obtained by working 1 mm protrusion from the apex with a #6 no Peeso reamer, and the root lengths of all teeth were fixed at a size of 15±1 mm. All roots were prepared with the TF Adaptive rotary instrument system in accordance with the procedures and standardization of apical foramen diameters was achieved.

Concentrations of NaOCl ranging from 0.5 to 6% have been used in the majority of cases reported with regenerative/revascularization.[25,26] NaOCl is cytotoxic to periodontal ligament cells and apical papilla stem cells (SCAPs), although at high concentrations (greater than 3%) it has a positive antimicrobial effect.[27] Therefore, it is recommended to use low concentrations of NaOCl. In the early days when RET procedures were introduced, some researchers used NaOCl and chlorhexidine together to perform irrigation. However, its use was abandoned because 2% chlorhexidine solution was found to have cytotoxic effects on stem cells.[28]

EDTA solution releases various growth factors found in dentin, thereby promoting the differentiation of stem cells attached to dentin surfaces into odontoblast-like cells. Trevino *et al.*[28] reported that irrigation protocol containing 17% EDTA preserves the viability of SCAPs. Martin *et al.*[29] also reported that final irrigation with 17% EDTA partially reversed the deleterious effects of the NaOCl solution on the survival and differentiation of SCAPs.

This study followed a standardized irrigation protocol based on previous studies. Root canals were irrigated with 2.5% NaOCl at a flow rate of 5 ml/min for 1 min, and then irrigated with 17% EDTA at a flow rate of 5 ml/min for 1 min. During the change of irrigation solutions, while the root canals were filled with solution, the solution was activated with irrigation activation devices for 10 seconds. Activation was carried out for a total of 30 seconds. Removed the effects of irrigation solutions associated with distilled water between passes. The canals were finally irrigated with 10 ml of distilled water to remove the prolonged effects of EDTA and NaOCl.

There is no consensus on the removal or preservation of the smear layer formed during root canal treatment. It is reported that irrigation solutions, medicaments and root canal fillers prevent penetration into dentinal tubules, reduce their bond strength against micromechanical forces, and therefore argued that it should be removed. Contrary, it is also reported that smear layer reduces dentin permeability and acts as a barrier against bacterial products, so it should not be removed because it prevents bacterial invasion into the dentinal tubules.[14, 17] It is known that due to the acidic nature of EDTA, which is used to remove the smear layer, calcium silicate-based cements have a negative effect on their hydration properties. This prevents the cements from bonding to the root canal. When EDTA cannot be effectively removed from the root canal in the final wash, it chelates with calcium ions released from the cement during the hydration of calcium silicate-based cements, resulting in the formation of hydrated products and also reduces the hardness and bond strength of tricalcium silicate-based cements.[30,31]

The findings of this study were found to be consistent with the results of previous studies.[32] Jiang *et al.*[32] compared different irrigation systems in removing dentin chips from the grooves artificially opened in the root canals and concluded that PUI group showed the highest removal scores, while the CSI group showed the lowest removal values. Arslan *et al.*[33] compared Qmix and different irrigation systems in removing the smear layer and concluded that use of Er:YAG and fiber tips showed more effective removal of the smear layer than the EA and CSI groups, and no statistically significant difference was found between the EA and CSI groups. These findings are consistent with this study.

Various methods such as digital photographs, stereomicroscopes, scanning electron microscopes, microcomputed tomography imaging and spiral computed tomographic imaging are used to evaluate the amount of medicament remaining in the root canal walls. Stereomicroscope has been used as an evaluation device in many studies on intracanal medicament removal. Therefore, in this study, a stereomicroscope was used to evaluate mTAP residues in the root canal walls.

Similar to current study, Plotino *et al.*[34] compared sonic and ultrasonic systems in intracanal medicament removal and reported that ultrasonic systems are more effective than sonic systems. In this study, with regard to root canal third, PUI had significantly higher intracanal medicament removal scores than EA, which is a sonic system. Typically, a sonic device operates at 1-8 kHz and an ultrasonic device operates at 25-40 kHz. This may be possible reason for the statistically significant results is the difference in operating speed between the devices.

Similar to previous studies[35], this study revealed that PUI removed TAP from the canal walls more effectively than CSI. However, no statistically significant difference was found between PUI, EV and EA groups. Akman *et al.*[35] also concluded that no significant difference was found between regions in CSI group. In that study, similar to this study, the CSI method did not show a statistically significant difference in the coronal, middle and apical thirds. In the PUI group, statistically significantly higher mTAP removal scores were observed in the apical and coronal triads. In this study, however, the PUI group did not show a statistically significant difference in the coronal, middle and apical third. This may be due to the decrease in the effectiveness of the PUI tip by contacting the canal wall as a result of the use of a tooth with complete root development in the study by Akman et al[35]. Finally, EV and EA showed significantly higher mTAP removal scores in the apical triad than in the middle and coronal third. In this study, while EA showed significantly lower scores in the apical triad compared to the coronal and middle triad, the EV did not show a significant difference in the coronal, middle and apical triad. This difference may have arisen due to the differences in the effectiveness of irrigation activation methods.

Berkhoff *et al.*[36] reported that TAP in the root canal could not be removed using EDTA and different irrigation activation methods. They also showed that more than 85% of the TAP remained in the dentin, and the majority of the TAP was found at depths greater than 350 µm. Contrary to these results, the use of different irrigation techniques in this study increased the removal of TAP from the root canals. However, in our study, mTAP was not labeled as radioactive and evaluation was made on photographs taken under 25x magnification under a stereomicroscope. This can be considered as a limitation of our study.

Conclusions

Intracanal medicament removal scores were significantly associated with irrigation system. PUI showed statistically significantly higher intracanal medicament removal efficiency than other irrigation methods. The least intracanal drug removal efficiency was seen with conventional syringe irrigation. While there was no difference between the coronal and middle thirds, statistically significantly less intracanal medicament removal was found in the apical third compared to the other regions. While adhesive fracture was the most common type of fracture in all groups, mixed fracture was the least common type of fracture.

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