Acta Odontologica Turcica
The official journal of Gazi University Faculty of Dentistry
DOI: https://doi.org/10.17214/gaziaot.945129

Original research article

Effect of root canal geometry and needle type on apical extrusion of irrigant: an *ex vivo* study

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ABSTRACT

OBJECTIVE: **The aim was to evaluate the effect of root canal geometry on the amount of apical extrusion of irrigant, by testing different tapers and needle types.**

MATERIALS AND METHOD: **Forty-three extracted single-rooted human mandibular premolar teeth were accessed. Experimental groups were instrumented to produce increasing amounts of taper in each successive group: Group 1 (#25/.02), Group 2 (#25/.04), Group 3 (#25/.06), and Group 4 (#25/.08) (n=43, each). Irrigation was done sequentially by using a 30-G open-ended flat needle, 30-G close-ended side-vented needle, and 27-G open-ended beveled needle. Flat and side-vented needles were each placed 3 mm short of the apex, while the beveled needle was placed as far as possible in the canal without binding. Extruded irrigant was collected in preweighed foam cubes. Statistical significance was set at $p<0.05$.**

RESULTS: **An increase in canal taper led to a decrease in the amount of extruded irrigant for the flat needle ($p<0.05$; Groups 1 and 2 versus 3 and 4) and side-vented needle ($p<0.05$; Groups 1 and 2 versus 4), but no significant effect was found for the beveled needle. The amount of extruded irrigant was greater with the flat than with the side-vented needle at all tapers and with the beveled needle at most tapers ($p<0.05$). The side-vented needle was generally associated with the least amount of extrusion.**

CONCLUSION: **Given a constant needle insertion depth, the amount of apically extruded irrigant decreased as canal taper increased. The greatest and least amounts of extrusion were generally observed with the flat and side-vented needle, respectively.**

KEYWORDS: **Needles; irrigation; root canal preparation; root canal therapy; sodium hypochlorite**

CITATION: Serçe Fikirli B, Altunkaynak B, Kayaoğlu G. Effect of root canal geometry and needle type on apical extrusion of irrigant: an *ex vivo* study. Acta Odontol Turc 2022;39(3):58-63

EDITOR: Mügem Aslı Ekici, Gazi University, Ankara, Turkey

FUNDING: None declared.

CONFLICT OF INTEREST: The authors declare no conflict of interest related to this study.

INTRODUCTION

Root canal irrigation and instrumentation are critical steps in endodontic treatment. During and after instrumentation, irrigating solutions are used to kill infectious microorganisms, dissolve necrotic and inflamed pulp tissues, prevent packing of hard and soft tissues in the apical region, and wash debris and smear from the root canal surface.[1] Various methods exist to deliver irrigant to the root canal. Irrigant may be injected directly by a syringe (positive pressure irrigation) or indirectly by a delivery cannula combined with a microsuction system (negative pressure irrigation). Alternatively, delivery may involve irrigant activation, such as by using vibrating tips and sonic or ultrasonic energy.[1,2] As the most commonly used irrigation method, classical needle irrigation (positive pressure irrigation) is effective and is the gold standard for comparison when testing any novel irrigation method.[1,3,4]

One undesired occurrence during endodontic treatment is apical irrigant extrusion, which refers to irrigant escape from the root canal to the periapical area. Extruded irrigant may be caustic (e.g., sodium hypochlorite), and irrigant extrusion carries risks of transferring debris to the periapex, irritating periapical tissues, and causing postoperative pain, swelling, flare-up, and delayed healing.[5,6] Several case reports have described instances of tissue damage and severe pain due to irrigant extrusion.[5,7-9] In addition, irrigant extrusion may be unreported or unnoticed by the clinician due to an absence of serious symptoms.[7] Thus, it is necessary to understand the causes of irrigant extrusion and implement measures to avoid the issue.

Received: May 30, 2021; Accepted: November 08, 2021
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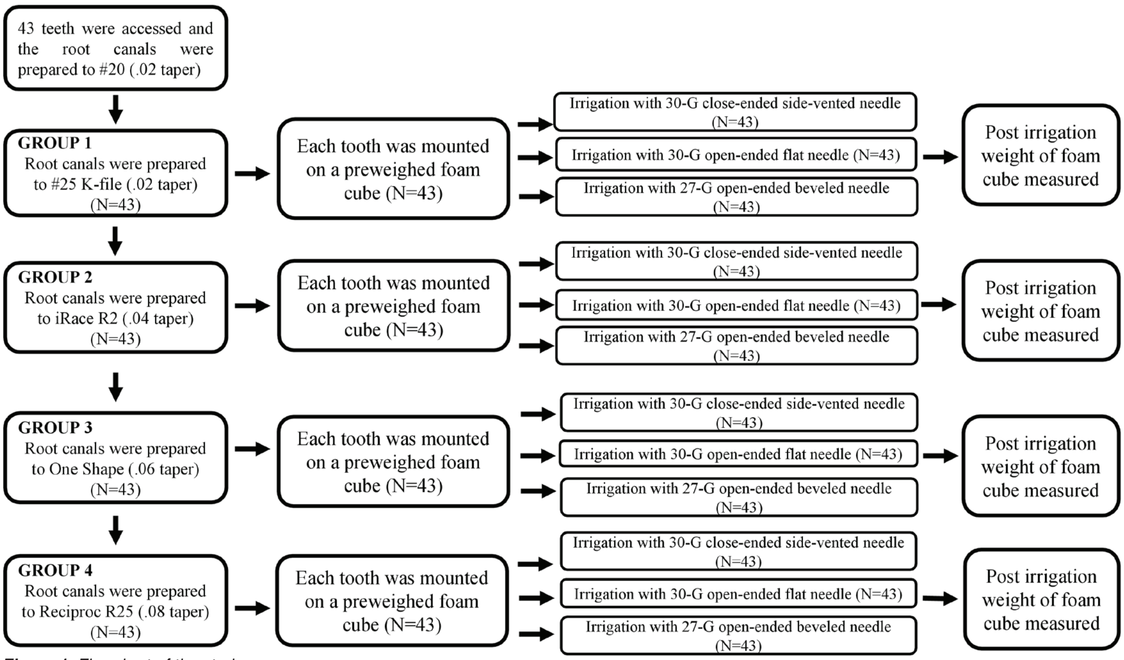

Figure 1. *Flowchart of the study*

Studies performed on extracted teeth or plastic blocks have identified operative and tooth-related factors that may be associated with increased risk of apical extrusion of the irrigant. Open-ended needles,[10-15] increased depth of needle insertion,[11,13,16] smaller apical preparation size,[11,12,14] higher injection flow rates,[13,14] positive irrigation pressure,[17] and manual agitation of irrigant[13] cause significantly greater amounts of apical irrigant extrusion. By contrast, the apical constriction diameter[12,13,18] and root canal curvature[11] had no significant effect on the amount of extruded irrigant. Mathematical calculations[19] and computational fluid dynamics (CFD) model analyses[20-22] have supported these experimental findings. Other than these well-known factors, a CFD study found that an increase in root canal taper caused a gradual decrease in apical pressure during irrigation with open- or closed-ended needles, which decreased the risk of irrigant extrusion.[23] That report, however, was based solely on theoretical analyses, and the results were not experimentally validated by testing on real teeth.

Therefore, the primary aim of the present study was to investigate the effect of root canal geometry (*i.e.*, different tapers) on the apical extrusion of irrigant. The secondary aim was to compare three different needle types for the amount of extruded irrigant.

Materials and Method

This study was approved by the Ethical Review Board of the Faculty of Dentistry at Gazi University, Ankara, Turkey (GÜDHKAEK.18.8/6; November 01, 2018).

Sample size calculation

Based on data from a pilot study, for an effect size of 0.25, type I error probability (α) of 0.05, statistical power ($1-\beta$) of 0.95, and 3 measurements (correlation among repeated measures taken as 0.5), the required number of teeth was 43 (actual power = 0.951; G-Power 3.1.9.2, Universität Kiel, Kiel, Germany).

Tooth selection

For this study, 43 extracted intact human mandibular premolar teeth with straight, single roots and canals were selected. Number and curvature (<10°) of the root canals were verified by taking digital radiographs.[24] Selected teeth measured 20 to 24 mm in length, had no visible cracks, no root canal calcification or resorption, and fully mature apices (*i.e.*, a #20 K-file could not pass beyond the apical foramen). Soft tissue remnants were curetted from root surfaces. Teeth were stored in physiologic saline solution until use. A flowchart showing the study design is presented in Figure 1.

Instrumentation of root canals

Coronal access cavity was prepared by using a high-speed fissure bur under water cooling. Endodontic working length (WL) was determined by placing a #10 K-file (Mani Inc., Tochigi, Japan) into the root canal, advancing it until the tip was just visible at the apex, and then subtracting 1 mm from this measurement. Canals were prepared up to #20 by using K-files with a quarter turn-and-pull motion, followed by copiously irrigation with 5.25% NaOCl between each file.

To overcome issues due to anatomical variations in teeth, a repeated-measures design was adopted, in which the same teeth were used throughout the experiment. Experimental groups were designed to produce a greater taper in each successive group. Commercial brands given below were used for obtaining standardized tapers only.

Group 1 (#25/.02). All 43 teeth were manually instrumented up to #25 K-file (0.02 taper) with a quarter turn-and-pull motion.

Group 2 (#25/.04). Same 43 teeth were instrumented by using iRace R2 files (#25/.04; FKG Dentaire, La Chaux-de-Fonds, Switzerland), which were mounted on an endodontic torque-controlled handpiece (Endo-Mate DT, NSK Nakanishi Inc., Tochigi, Japan) and operated according to the manufacturer's recommendations (600 rpm speed and 1.5 Ncm torque).

Group 3 (#25/.06). Same 43 teeth were instrumented by using One Shape files (#25/.06; MicroMega, Besançon, France), which were mounted on an endodontic torque-controlled handpiece (Endo-Mate DT) and operated according to the manufacturer's recommendations (350 rpm speed and 2.5 Ncm torque).

Group 4 (#25/.08). Same 43 teeth were instrumented by using Reciproc R25 files (#25/.08 taper at the apical 3 mm, then taper uniformly decreased (.043 taper) to D16; VDW, Munich, Germany), which were mounted on an endodontic torque-controlled handpiece (X-Smart Plus, Dentsply Maillefer, Ballaigues, Switzerland) and operated according to the manufacturer's recommendations (Reciproc mode).

The instrument profiles described above, therefore the geometry changes in the root canal after each preparation step is shown in Figure 2.

After instrumentation, each group was cleared of smear and debris through irrigation with NaOCl (2 mL, 5.25%, 2 min) and EDTA (2 mL, 17%, 2 min). Each group was washed in an ultrasonic bath in water for 2 min (Eurosonic Micro, Euronda, Vicenza, Italy). Root surfaces were blotted dry with gauze, and apical patency was checked by extruding a #10 K-file to 1 mm beyond the WL.

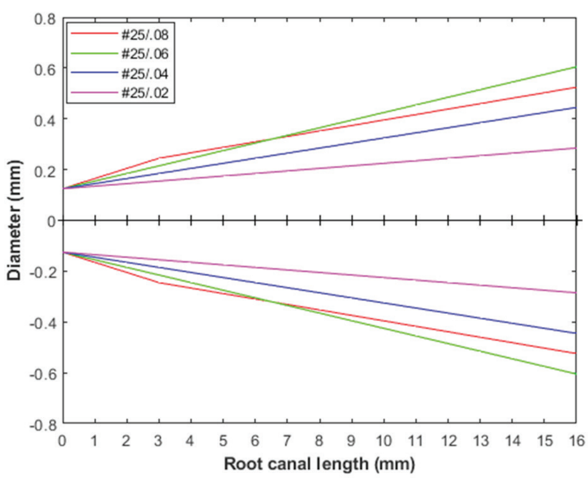

Figure 2. *The profile of each successive instrument is shown in the figure. Note that the #25/.08 file has a decreased taper after 3 mm (D3), and its diameter is smaller than that of the #25/.06 file by D7. Because the coronally larger .06 taper file was used before the .08 taper file, the eventual instrumentation geometry after the .08 taper file reflects a combination of the profiles of the two files.*

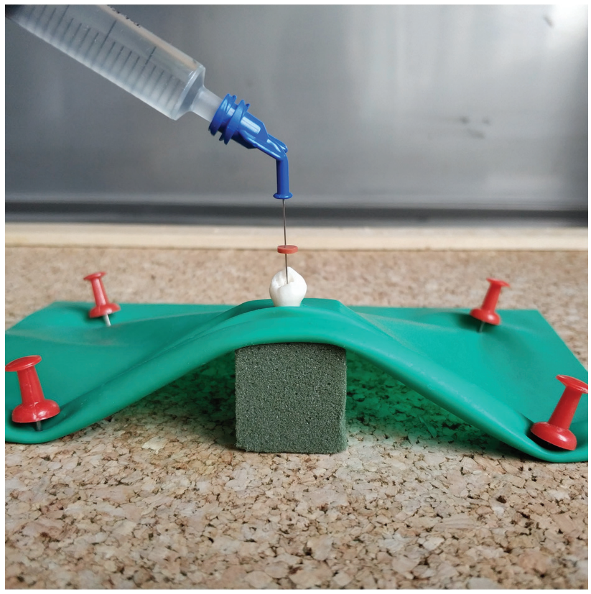

Figure 3. *Experimental setup showing tooth inserted through a hole punched on a rubber-dam sheet and embedded into a preweighed floral arrangement foam cube, in which extruded irrigant is collected*

Irrigation protocols

Each instrumentation group was irrigated by using a 30-G open-ended flat needle (NaviTip, Ultradent Products Inc, South Jordan, UT, USA), 30-G close-ended side-vented needle (Endo-Top, Cerkamed, Stalowa Wola, Poland), and 27-G open-ended beveled needle (Genject, Genject AŞ, Ankara, Turkey). Flat and side-vented needles were each placed 3 mm short of the WL, while the beveled needle was placed as far as possible into the canal without binding. In all cases, a 2-mL injector was used. All three needles were placed loosely in the canal and moved with an up-and-down motion at 4-mm amplitude while irrigating. Delivery speed was 2 mL/min, and a total of 6 mL of 5.25% NaOCl was used for irrigation in each experiment.

The rationale behind the set needle penetration depths relied on the diameter differences among the tested needle types. For example, when using a 30-G irrigation needle (outer Ø: 0.31 mm) in the 25/.02 taper group, the maximum point that the needle could reach without binding was theoretically ≈3 mm short from the apex. Therefore, in all groups, irrigation needles of this diameter (30-G) were always positioned 3 mm short from the apex. On the other hand, when a 27-G dental injector (outer Ø: 0.40 mm) was used, irrigation was performed by positioning the needle to the last point it could reach freely without binding the canal walls.

Irrigant extrusion measurement

Flower arrangement foam was used for measuring the volume of apically extruded irrigant, as described previously.[10] Briefly, each tooth was inserted through a hole punched on a rubber-dam sheet and embedded into a preweighed foam cube to the cementoenamel level (Figure 3). Corners of the rubber-dam sheet were fixed on a corkboard by pins. After irrigation, the tooth was detached from the foam cube, which was weighed on a precision balance with a sensitivity of 10^{-4} g (XB 220A; Precisa, Dietikon, Switzerland). The mean of 3 measurements was calculated and subtracted from the initial weight. The difference was recorded as the weight of extruded irrigant. Before the experiment, a pilot test was done to confirm that no leakage due to overflowing irrigant occurred through the rubber dam and the root surface interface.

Statistical analysis

Normality and variance equality of the data were checked by using the Kolmogorov-Smirnov and Levene tests, respectively. One-way analysis of variance (ANOVA) followed by Tukey test was used to compare between groups (taper comparisons), and repeated-measures ANOVA followed by Bonferroni test was used to compare within groups (needle comparisons). SPSS statistical software package (SPSS Inc. Version 20, Chicago, IL, USA) was used for all analyses, and statistical significance was set at $p<0.05$.

Results

Taper comparisons (intergroup comparisons)

Differences between groups were found when the flat ($p<0.01$) or side-vented needle was used ($p<0.05$) but not when the beveled needle was used ($p>0.05$, one-way ANOVA) (Table 1). For the first two needle types, the smaller canal taper yielded a greater amount of extruded irrigant compared to the greater canal taper. Significant differences were found between Groups 1 and 2 compared to Groups 3 and 4 for the flat needle, and between Groups 1 and 2 compared to Group 4 for the side-vented needle ($p<0.05$).

Needle comparisons (intragroup comparisons)

Differences were found between needle types in each group ($p<0.01$, repeated-measures ANOVA, Table 2), with the flat needle consistently yielding a greater amount of extruded irrigant than either the side-vented or beveled needles in the first three groups ($p<0.05$). In the last group (#25/.08), the side-vented needle yielded a smaller amount of extruded irrigant than the other needle types ($p<0.05$).

Table 1. *Statistical comparisons among groups (different tapers) for each needle type*

Needle type	Group	N	Mean (g)	SD	F§	p
Open-ended flat needle (30-G)	1 (#25/.02)	43	1.03[a]	0.61	8.78**	0.001
	2 (#25/.04)	43	1.07[a]	0.61		
	3 (#25/.06)	43	0.73[b]	0.59		
	4 (#25/.08)	43	0.56[b]	0.28		
Close-ended side-vented needle (30-G)	1 (#25/.02)	43	0.47[a]	0.35	2.84*	0.040
	2 (#25/.04)	43	0.45[a]	0.34		
	3 (#25/.06)	43	0.36[ab]	0.42		
	4 (#25/.08)	43	0.28[b]	0.22		
Open-ended bevelled needle (27-G)	1 (#25/.02)	43	0.53	0.53	0.68	0.568
	2 (#25/.04)	43	0.45	0.36		
	3 (#25/.06)	43	0.55	0.58		
	4 (#25/.08)	43	0.61	0.63		

**p < 0.05, **p < 0.01; §One-way ANOVA; Different superscript letters represent statistically significant difference between groups (Tukey test, p < 0.05); SD: standard deviation*

Table 2. *Statistical comparisons within each group for different needle types*

Group	Needle type	N	Mean (g)	SD	F§	p
1 (#25/.02)	Open-ended flat needle (30-G)	43	1.03[a]	0.61	22.61**	0.000
	Close-ended side-vented needle (30-G)	43	0.47[b]	0.35		
	Open-ended beveled needle (27-G)	43	0.53[b]	0.53		
2 (#25/.04)	Open-ended flat needle (30-G)	43	1.07[a]	0.61	22.50**	0.000
	Close-ended side-vented needle (30-G)	43	0.45[b]	0.34		
	Open-ended beveled needle (27-G)	43	0.45[b]	0.36		
3 (#25/.06)	Open-ended flat needle (30-G)	43	0.73[a]	0.59	13.88**	0.000
	Close-ended side-vented needle (30-G)	43	0.36[b]	0.42		
	Open-ended beveled needle (27-G)	43	0.55[b]	0.58		
4 (#25/.08)	Open-ended flat needle (30-G)	43	0.56[a]	0.28	25.21**	0.000
	Close-ended side-vented needle (30-G)	43	0.28[b]	0.22		
	Open-ended beveled needle (27-G)	43	0.61[a]	0.63		

***p < 0.01; §Repeated Measures ANOVA; Different superscript letters represent statistically significant difference between groups (Bonferroni correction, p < 0.05); SD: standard deviation*

Discussion

The main finding in this study was that the amount of extruded irrigant decreased with an increase in canal taper. This result was evident when needle insertion depth was constant, as in the case of the flat and side-vented needles. The secondary finding was that the flat needle caused a greater amount of irrigant to be extruded compared to the side-vented or beveled needle for most tapers. Thus, the side-vented needle was generally the safest needle.

The main finding of this *ex vivo* study supports the findings of a previous CFD study: namely, that an increase in root canal taper reduces the apical pressure and, therefore, the risk of solution extrusion during irrigation.[23] As in the Boutsioukis study,[23] this result was only true when the needle insertion depth remained constant and was not seen when the beveled tip was used. This result may be due to the effects of other variables, such as the different gauge size and increasing insertion depth of the needle with the stepwise increase in taper. As taper increased, the beveled needle was inserted deeper into the canal, and the tip approached the foramen and remained in contact with the canal walls. This situation may have resulted in the jammed irrigant being unable to pass through the canal in a coronal direction; thus, the amount of extrusion was not lessened despite the increased taper. The 27-G beveled needle, with its specified mode of use, was tested because it is the accepted method of irrigation in the authors' endodontic clinics at the Department of Endodontics of the Faculty of Dentistry at Gazi University, Ankara, Turkey.[25] It can be concluded that the canal taper has no significant effect on irrigant extrusion when a beveled needle is inserted progressively deeper at each increasing taper.

The effect of coronal preflaring (not presenting an exactly continuous taper throughout) was investigated previously for debris extrusion.[26,27] In these studies, coronal preflaring performed before canal instrumentation by using high-speed endodontic access burs or Gates-Glidden drills reduced the amount of apical debris extrusion. These findings may be explained, in part, by the effect of the achieved canal geometry, as in the current study. It is possible that the extruding irrigant may also mediate debris extrusion.

Regarding the effect of needle type, our findings are consistent with those of previous *ex vivo* studies, as a greater amount of irrigant extrusion was found with an open-ended flat needle compared to a close-ended side-vented needle.[10-13,15] Our findings also confirm findings of previous CFD studies, in which different flow patterns were observed between these two needle types. Open-ended needles (flat or beveled), by creating jet towards the apex, theoretically exhibit more irrigant replacement at the apical front, higher apical pressure, and greater risk of extrusion compared to close-ended side-vented needles.[20-22]

The strengths of this study were its relatively high statistical power (1-β = 95%) and elimination of possible variances between specimens by using the same set of teeth repeatedly in all experimental groups (tapers and needle types). Additionally, a practical method was applied for the collection and measurement of extruded irrigant. This method was used previously by others.[10,28,29] In a methodological study, the extrusion pattern of irrigant obtained with the foam cube method showed good correlation with the pattern obtained by the traditional glass vial collection method.[30] Weaknesses of the study include the lack of periodontal tissue pressure, the use of a single type of tooth with straight roots only, and the performance of the experiment by a single operator. Another weakness of this study was that only irrigant extrusion was measured and debris extrusion was not evaluated. An additional limitation was the negligence of the gravity force, which can have a significant effect on apical irrigant extrusion.[28]

As for the clinical significance of the findings of this study, we can say that the risk of irrigant extrusion is relatively high in the initial stages of preparation, and this risk decreases inversely as the taper increases. Increase in the taper possibly provides room for escape for the irrigant coronalwards. At this point, preflaring may be useful. Jet effect is also more pronounced in the open-ended flat needle, and is associated with increased irrigant extrusion. So, from the irrigant extrusion aspect, the side-vented needle should be preferred clinically.

Conclusion

In this *ex vivo* study, the root canal geometry affected irrigant extrusion. When the needle depth remained unchanged, an increase in root canal taper was inversely related to the amount of apical irrigant extrusion. The flat needle extruded more irrigant than the side-vented needle at all tapers and extruded more irrigant than the beveled needle at most tapers. Overall, the safest needle was the side-vented needle.

Acknowledgments

This study constitutes a part of the specialty dissertation thesis entitled 'Kök kanal geometrisinin apikalden irrigan ekstrüzyonuna etkisi: *in vitro'* by Büşra Serçe Fikirli; Gazi University, 2019, Ankara.

This study was presented as an oral presentation in the 20th Scientific Congress of the Asian Pacific Endodontic Confederation, 24-27 April 2019 İstanbul, Turkey.

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Kök kanal geometrisinin ve iğne tipinin apikalden irrigan taşmasına etkisi: *ex vivo* çalışma

Özet

Amaç: Bu çalışmanın amacı farklı koniklik açıları ve iğne tiplerini test ederek, kök kanal geometrisinin apikalden taşan irrigan miktarına etkisini değerlendirmektir.

Gereç ve Yöntem: Kırk üç adet çekilmiş tek köklü insan mandibular küçük azı dişi kullanıldı. Deney grupları, birbirini takip eden her grupta artan koniklik üretecek şekilde enstrümante edildi: Grup 1 (#25/.02), Grup 2 (#25/.04), Grup 3 (#25/.06) ve Grup 4 (# 25/.08) (n=43, her grupta). İrrigasyon, sırasıyla, 30-G açık-düz uçlu iğne, 30-G kapalı uçlu yandan perfore iğne ve 27-G açık-bevel uçlu iğne kullanılarak yapıldı. Açık-düz uçlu ve kapalı uçlu yandan perfore iğneler apeksten 3 mm kısa olacak şekilde yerleştirilirken, açık-bevel uçlu iğne kanal içerisinde sıkışmadan ilerleyebileceği son noktaya kadar yerleştirildi. Taşan irrigan önceden tartılmış sünger küplerde toplandı. İstatistiksel anlamlılık değeri $p<0.05$ olarak belirlendi.

Bulgular: Kanal konikliğindeki artış, açık-düz uçlu iğne ($p<0.05$, Grup 1 ve 2 ile Grup 3 ve 4 arasında) ve kapalı uçlu yandan perfore iğne ($p<0.05$, Grup 1 ve 2 ile Grup 4 arasında) için taşan irrigan miktarında azalmaya neden oldu. Buna karşın, açık-bevel uçlu iğne için anlamlı bir etki görülmedi. Taşan irrigan miktarı, tüm koniklik açılarında, açık-düz uçlu iğne kullanıldığında kapalı uçlu yandan perfore iğneye göre ve çoğu koniklik açısında açık-bevel uçlu iğneye göre daha fazlaydı ($p<0.05$). Kapalı uçlu yandan perfore iğne genellikle en az irrigan taşmasıyla ilişkiliydi.

Sonuç: İğne yerleştirme derinliği sabit olduğunda, apikalden taşan irrigan miktarı, kanal konikliği arttıkça azaldı. En fazla ve en az taşma genellikle, sırasıyla, açık-düz uçlu ve kapalı uçlu yandan perfore iğnede gözlendi.

Anahtar Kelimeler: İğneler; irrigasyon; kök kanalını hazırlama; kök kanal tedavisi; sodyum hipoklorit