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ORIGINAL ARTICLE

Comparison of the efficacy of TruNatomy, side-vented, and open-ended irrigation needles in apical debris extrusion: an in-vitro study

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Abstract

The aim of this in vitro study was to evaluate the effect of irrigation needles with different designs on the amount of apically extruded debris during root canal treatment. TruNatomy, open-ended, single-side-vented, and double-side-vented irrigation needles were assessed. Eighty extracted human mandibular incisors with single roots and single canals, removed for periodontal or orthodontic reasons, were used. The teeth were randomly assigned to four groups ($n = 20$) according to the irrigation needle type: open-ended, single-side-vented, double-side-vented, and the TruNatomy needle. Apically extruded debris was collected using the Myers and Montgomery model and weighed with an electronic microbalance. Data were analyzed using the Shapiro–Wilk and Kruskal–Wallis tests ($p < 0.05$). No statistically significant differences were found among the groups regarding the amount of apically extruded debris. Among the needle designs, the TruNatomy group exhibited the highest extrusion values, followed by the open-ended, double-side-vented, and single-side-vented needle groups. All needle designs resulted in some degree of apical debris extrusion. Although neither contemporary nor conventional needle designs significantly influenced the amount of debris extruded during canal irrigation, the observed differences in extrusion levels should be considered when selecting irrigation needles for clinical use.

Keywords Dental irrigation · Dentinal debris · Dental instruments · TruNatomy needle · Apical debris extrusion

Introduction

Apical extrusion of debris during chemomechanical preparation of root canals is one of the undesirable complications of endodontic treatment. The organic components of extruded debris—consisting of pulp tissue remnants, necrotic tissue residues, microorganisms and their by-products, dentin chips, and irrigating solutions—come into direct contact with the periapical tissues [1, 2]. Extrusion disrupts the balance between the root canal microbiota and the host defense mechanisms, leading to acute inflammatory reactions in the periapical region [1]. Consequently, patients may experience acute postoperative pain, flare-up episodes, and delayed healing. Previous studies have demonstrated that nearly all instrumentation techniques are associated with some degree of debris extrusion [3, 4]. Several factors influence the amount of apically extruded debris, including instrument design, motion kinematics, technique of use, irrigation protocols and devices, needle design, needle penetration depth, and the condition of the apical constriction. Effective irrigation techniques are crucial for achieving adequate disinfection and removing residual tissues from areas inaccessible to mechanical instruments, such as the apical third, isthmuses, and lateral canals [2]. Irrigation solutions are typically delivered into the canal using irrigation needles, and the design of the needle tip influences the direction of irrigant flow, pressure distribution against canal walls in the apical region, and irrigant velocity [2, 5].

An ideal irrigation needle should possess side-vented openings, a sufficiently small tip size for safety, and a configuration that allows positioning as close to the apical area as possible [3]. Minimizing debris extrusion is essential for reducing postoperative complications [4]. To achieve this,

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irrigation needles with various diameters and designs have been developed [3, 5]. Based on their tip design, needles are broadly categorized into open-ended and closed-ended configurations. Closed-ended needles can be further subdivided into single-side-vented, double-side-vented, and multivented designs. While traditional irrigation needles are made of stainless steel, modern polypropylene needle tips are increasingly preferred because of their flexibility. TruNatomy (Dentsply Sirona, Tulsa, OK) is an example of a recently introduced polypropylene irrigation tip; it is flexible, manufactured from polypropylene, has a 4% taper, and corresponds to 30-G [6]. Although side-vented needles have become the gold standard for reducing the extrusion of debris and irrigants, several studies have shown that these designs generate considerable shear stress on canal walls near the needle tip. This may result in insufficient irrigation in the area apical to the needle tip [7]. In addition, there is an ongoing debate regarding the potential of this design to leave a "vapor lock" zone apical to the needle tip, resulting in insufficient irrigant exchange in this region. Computational Fluid Dynamics studies by Loroño et al. [8] demonstrated that although side-vented needles may eliminate vapor lock in the main canal, they are ineffective in removing gas bubbles within complex apical ramifications, with irrigant exchange being limited to only 1–1.5 mm beyond the needle tip. These findings indicate that irrigation efficacy cannot be attributed solely to needle design, but rather should be considered as a comprehensive strategy. As emphasized by Marques et al. [9], the dynamic interaction between irrigant type, concentration, needle geometry, and activation methods influences not only microbial elimination, but also alters the structural, chemical, and mechanical properties of dentin, thereby playing a critical role in restorative sealing quality and long-term clinical outcomes.

Regarding clinical positioning, open-ended needles are recommended to be used 2–3 mm short of working length, whereas closed-ended needles should be positioned 1 mm short of working length [6].

The present study aimed to evaluate the effect of four irrigation needle designs on the amount of apically extruded debris during irrigation. The null hypothesis was that there would be no significant difference among the needle designs in terms of the amount of debris extruded apically.

Materials and methods

Sample selection

Ethical approval for this study was obtained from the Akdeniz University Clinical Research Ethics Committee on (31.07.2025/757) and the study was conducted in accordance with the ethical principles of the 1964 Declaration of Helsinki.

The sample size was calculated using G*Power 3.1 software (Heinrich Heine University, Düsseldorf, Germany) based on data from previous studies [10, 11]. As a direct power analysis for the Kruskal–Wallis test is not available in G Power, the calculation was conducted based on the equivalent one-way analysis of variance (ANOVA). A large effect size (Cohen's $f = 0.40$) was assumed in line with effect sizes reported in previous studies with comparable quantitative outcomes. With a significance level of 0.05, a statistical power of 80%, and four independent groups, the required total sample size was estimated to be 76 teeth. To compensate for potential specimen loss and to ensure equal group sizes, a total of 80 teeth were included in the study. The teeth were divided into four groups, with 20 teeth in each group.

A total of 80 extracted human mandibular incisors were used, all of which were single-rooted, caries-free, unrestored, had no history of root canal treatment, and exhibited no cracks or fractures in the root region. Teeth were extracted for periodontal or orthodontic reasons and were obtained from the Department of Oral and Maxillofacial Surgery at Akdeniz University Faculty of Dentistry.

Following extraction, hard and soft tissue remnants on the root surfaces were removed using an ultrasonic scaler. Each tooth was examined under an operating microscope to confirm the presence of a single apical foramen. Teeth meeting the inclusion criteria were stored in normal saline until testing began.

Tooth preparation

All teeth were decoronated at the incisal edge to obtain a standardized root length of 16 ± 1 mm. Access cavities were prepared using a diamond round bur (Bosphorus, Türkiye) mounted on a high-speed handpiece. Working length was established by inserting a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) into the canal until the tip was just visible at the apical foramen; the working length was set at 1 mm short of this point.

The minimum apical size was verified by advancing a #15 K-file to working length. Teeth in which the file extended beyond the foramen were excluded from the study. This procedure ensured standardization of the apical foramen diameter across all specimens.

Preparation of the experimental setup

The method described by Myers and Montgomery [9] was used to collect debris extruded during instrumentation, employing Eppendorf tubes sealed with rubber stoppers.

Each tube was weighed three times without the stopper, and the mean value was recorded using an electronic microbalance (Shimadzu AP225WD, Kyoto, Japan) with a sensitivity of 0.00001 g.

A hole was created in the center of each rubber stopper using a heated instrument, and the teeth were inserted through the opening and positioned so that the cementoenamel junction was aligned with the stopper surface [10]. A rubber dam sheet (Nic Tone, Mexico) was placed around the root to prevent irrigant leakage onto the outer surface of the tube.

To ensure pressure equalization between the internal and external environments, a needle (Zheji Medicines and Health Products Co. Ltd, ZMC, China) was inserted through the rubber stopper.

Group allocation, Canal preparation, and Irrigation procedure

Before canal preparation, the teeth were randomly assigned to four groups ($n = 20$) according to the design of the irrigation needle to be used. Irrigation procedures were performed using four different 30-G needles with distinct designs:

- *Group 1*: Open-ended notched irrigation needle (Endo-Top, Cerkamed, Stalowa Wola, Poland)
- *Group 2*: Closed-ended single-side-vented irrigation needle (Scope Endo Fx Ject, Türkiye)
- *Group 3*: Closed-ended double-side-vented irrigation needle (Double Sideport, Raito, China)
- *Group 4*: TruNatamoy needle (Dentsply Sirona, Tulsa, OK) (Double-sided, side-vented, silicone, angled irrigation needle)

For Group 1, the open-ended needle was positioned 3 mm short of the working length. For Groups 2, 3, and 4, the irrigation needles were positioned 1 mm short of the working length.

Root canals were prepared using the ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) rotary system in the sequence X1, X2, and X3, following the manufacturer's instructions.

During canal preparation, irrigation was performed using distilled water. After each file, 2 mL of irrigating solution was applied, with 1 mL used for the final irrigation and 0.5 mL for the apical flushing step, resulting in a total of 5 mL of irrigant per canal. To standardize irrigation pressure, the 2 mL of irrigant applied after each file was delivered over 30 s, while the 1 mL used for the final irrigation was applied over 15 s [12].

Measurement of debris extrusion

After the teeth were removed from the tubes, the tubes containing the extruded debris were placed in an incubator (Sanyo Electronics, Japan) at 70 °C for three days to ensure the complete evaporation of any remaining irrigant. Following incubation, each tube was weighed three times, and the mean value was recorded as the final weight. During all weighing procedures, the ambient temperature was maintained at 25 °C and the relative humidity ranged between 58 and 65%.

The amount of extruded debris was calculated by subtracting the initial empty tube weight from the final weight of the tube containing the dried debris.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 20.0 (IBM Corp., Armonk, NY, USA). The distribution of the data was assessed with the Shapiro–Wilk normality test. As the data did not follow a normal distribution ($p < 0.05$), the Kruskal–Wallis test was used as a nonparametric method to evaluate differences among the groups. No statistically significant differences were found between the groups ($p > 0.05$).

Results

All 80 teeth allocated to the four groups were included in the analysis of apically extruded debris. According to the descriptive statistics, the highest amount of debris extrusion occurred in the following order: TruNatomy > open-ended > double-side-vented > single-side-vented. According to the Shapiro–Wilk test, the data were not normally distributed. ($p < 0.05$), and the corresponding statistical outcomes are presented in Table 1.

When the amount of apically extruded debris was compared among the groups, no statistically significant differences were observed ($p = 0.824$). Descriptive statistical values for each group are shown in Table 2.

Table 1 Results of normality test

	Shapiro–Wilk		
Group	Statistic	*Df*	Sig
Group 1 (open-ended)	0.901	20	0.044
Group 2 (side-evented)	0.970	20	0.753
Group 3 (double side-vented)	0.927	20	0.134
Group 4 (TruNatomy irrigation needle)	0.983	20	0.969

Df The number of observations per group

Sig Significance

Table 2 Descriptive values for each group

Group	Debris extrusion (µg) median (IQR)
Group 1 (open-ended)	0.00043 (0.00059)
Group 2 (side-vented)	0.00038 (0.00020)
Group 3 (double side-vented)	0.00039 (0.00054)
Group 4 (TruNatomy needle)	0.00046 (0.00024)

IQR interquartile range

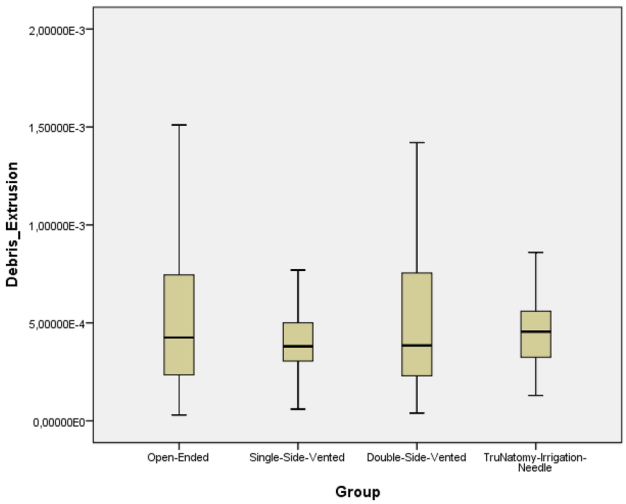

Fig. 1 Boxplot graphics for each group

In the box plot analysis, the TruNatomy irrigation needle group showed the highest median value with a moderate degree of data dispersion. The open-ended and double-side-vented groups followed, both exhibiting wider data spread and greater variability. The single-side-vented needle group demonstrated the lowest median value and the narrowest interquartile range (IQR), indicating the most homogeneous distribution among the groups (Fig. 1).

Discussion

Irrigation needles are produced with various tip designs to enhance canal cleanliness and disinfection while minimizing the risk of damage to periapical tissues. The literature includes studies evaluating the effect of different irrigation needle designs on the amount of apically extruded debris during canal preparation. However, research on the newly introduced TruNatomy needle remains limited, and no published study has yet investigated its effect on apical debris extrusion. [3, 5, 13–15]. In this ex vivo study, the effects of irrigation performed with four irrigation needles of different designs on the amount of apically extruded debris during root canal treatment were evaluated. The findings demonstrated that all groups exhibited a certain level of debris extrusion; however, no statistically significant differences were observed among the groups ($p = 0.824$). Accordingly, the null hypothesis stating that there would be no difference in the amount of apically extruded debris among the irrigation needle designs was accepted.

According to the descriptive statistics, the TruNatomy needle exhibited the highest debris extrusion, followed by the open-ended, double-side-vented, and single-side-vented needles. Although not statistically significant, the higher extrusion tendency observed with TruNatomy may be related to its 0.04 taper design. Dai et al. [7] reported that a reduction in the reflux area between the needle and the canal wall may lead to an increase in apical pressure. The conical geometry of the TruNatomy needle, which allows closer adaptation to the canal walls, may restrict coronal backflow of the irrigant and facilitate a more effective transmission of irrigation pressure toward the apical region. This hydrodynamic behavior may explain the relatively higher debris extrusion values observed, despite the flexible structure of the needle. There are currently no studies in the literature that directly evaluate apical debris extrusion using the TruNatomy irrigation needle. The two published studies involving the TruNatomy needle have focused primarily on its irrigation efficiency. Baasch et al. reported that the TruNatomy needle achieved cleaning and bacterial reduction comparable to other needle designs along the full canal length (98.9%); however, when only the apical segment and the isthmus region were evaluated, the TruNatomy needle exhibited a significantly lower rate of bacteria-negative outcomes (28%) compared with open-ended needles (61%) [6]. The closed-ended and tapered design of the TruNatomy needle limits irrigant exchange to only 1–1.5 mm beyond the needle tip, resulting in a flow pattern that restricts the delivery of fresh solution beyond this distance. Loroño et al. demonstrated that although side-vented needles can reduce vapor lock in the main canal, they are insufficient to overcome the air lock barrier within apical ramifications, providing a mechanistic explanation for the observed apical disinfection deficiency [8]. Accordingly, in the present study, although the apical pressure generated in the TruNatomy group was sufficient to extrude debris, it was not capable of producing adequate dynamic turbulence within the ramifications, thereby limiting disinfectant penetration. When these findings are considered together, it becomes evident that the amount of debris extruded apically does not directly correlate with apical cleaning efficacy or bacterial elimination.

Silva et al. [5], evaluated the effects of different irrigation needle designs, open-ended, side-vented, and double-side-vented, on apical debris and irrigant extrusion. Their findings indicated that the needle design significantly influences the

amount of material extruded apically. In particular, double-side-vented needles were reported to markedly reduce apical extrusion by distributing irrigant flow more evenly within the canal. Bürklein and Schäfer reported that open-ended needles caused greater debris extrusion compared with laterally vented needles. Similarly, in a study conducted by Altundasar et al. [14] the amounts of apical debris and irrigant extrusion produced during irrigation with open-ended and side-vented needles were compared while using ProTaper and RaCe rotary systems. The highest extrusion was observed in the ProTaper group irrigated with an open-ended needle, whereas the lowest extrusion occurred in the RaCe group irrigated with a side-vented needle. Although open-ended needles are generally reported to generate higher apical pressure, Boutsioukis et al. [15], demonstrated that open-ended needles with a notched design may produce lower jet velocity and apical pressure than flat or beveled tips; this characteristic may have reduced the extrusion potential of the notched open-ended needle in the present study to a level comparable with that of closed-ended needles.

In line with the present study, Uzunoğlu et al. [13], compared the ProTaper Next and OneShape Apical systems using a standard open-ended needle and a closed-ended side-vented Max-I-Probe needle; they reported that all groups produced a certain amount of debris extrusion, although no statistically significant differences were detected. In our study as well, the single- and double-side-vented needle groups exhibited lower extrusion levels than the open-ended needle group, although the difference was not statistically significant.

In a similar in vitro investigation, Habeeb [3] evaluated the effects of different irrigation needle designs (Max-I-Probe, NaviTip Fx, and IrriFlex) and two penetration depths (1 mm and 3 mm) on apical debris extrusion. According to the results, all needles produced some degree of extrusion; however, both needle design and penetration depth significantly influenced the extrusion amount. The highest debris extrusion was recorded with the NaviTip Fx needle positioned at 1 mm, whereas the lowest extrusion occurred with the flexible polypropylene IrriFlex needle positioned at 3 mm. The author concluded that flexible, double–side-vented needle designs distribute irrigant flow more evenly, reduce apical pressure, and consequently minimize the risk of apical extrusion. The use of different irrigation needle types, the evaluation of varying needle penetration depths, and the lack of standardization of apical preparation diameters represent the main methodological differences compared with the present study. Each of these factors may influence the amount of apical extrusion and may, therefore, explain the discrepancies among the findings.

Although the amounts of apical extrusion measured in the present study remained in the sub-microgram range and no statistically significant differences were detected among the groups, the clinical and biological implications of these findings should be carefully considered. Tanalp and Güngör [16] emphasized that even minimal amounts of extruded debris may trigger acute inflammatory responses in the periapical tissues due to the presence of microorganisms, necrotic pulp remnants, and chemical irrigants.

In our study, the method described by Myers and Montgomery was selected for collecting the extruded debris [17]. The main limitation of this method is its inability to simulate the pressure conditions of the periapical tissues and the apical region. To prevent the possibility of sodium hypochlorite crystallization altering the weight of dentin debris and compromising the reliability of the measurements, distilled water was used as the irrigating solution [16].

Chow et al. reported in their irrigation studies using different needle gauges that smaller-diameter needles deliver the irrigant more effectively to the apical region [18]. Similarly, Guerreiro-Tanomaru et al. stated that 30-G needles provide the highest cleaning efficiency in the apical third [19]. In the present study, the use of 30-G needles was likewise preferred to maximize the ability of the irrigant to reach the apical region. Although all needle types used in this study had the same tip diameter (30-G), the TruNatomy needle differs in that it has a conical design. Boutsioukis et al. [15], reported that open-ended needles generate a strong apically directed jet, which enhances irrigant replacement, but is accompanied by a significant increase in apical pressure. In contrast, side-vented needles redirect the flow toward the canal walls, resulting in lower apical pressure and more limited irrigant exchange in the apical region. Based on these findings, specific needle insertion depths have been recommended to balance effective irrigant exchange with apical safety. Accordingly, in the present study, the open-ended needle was positioned 3 mm short of the working length (WL), whereas the TruNatomy and other side-vented needles were positioned 1 mm short of the WL.

The limitations of this study include its in vitro nature, the manual control of irrigation pressure, and the use of distilled water as the sole irrigant. In a real clinical setting, factors such as the viscosity, temperature, and surface tension of different irrigation solutions may also influence the amount of apical extrusion and should therefore be taken into consideration. Further studies simulating periapical tissue resistance and using NaOCl in combination with an appropriate neutralizing agent in the collection vial to better simulate clinical conditions.

Clinical relevance

This study provides the first data on apical debris extrusion associated with the recently introduced TruNatomy irrigation needle. The study may assist clinicians in making informed decisions when considering newer irrigation

devices, while highlighting the importance of careful irrigation protocols to minimize the risk of apical extrusion.

Conclusion

Within the limitations of this ex vivo study, all tested irrigation needle designs caused apical debris extrusion during chemomechanical root canal preparation, and despite a higher extrusion tendency observed with the TruNatomy needle, no statistically significant differences were found among the groups. These findings suggest that apical debris extrusion may be influenced by factors, such as needle tip design, flexibility, and flow dynamics, and that in clinical practice, needle selection should also consider accessibility and ease of use.

Data availability The datasets can be obtained from the corresponding author upon reasonable request.

Declarations

Conflict of Interest The authors declare that there is no conflict of interest related to this study.

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References

1. Ahmad MZ, Sadaf D, MacBain MM, Merdad KA. Effect of mode of rotation on apical extrusion of debris with four different single-file endodontic instrumentation systems: systematic review and meta-analysis. Aust Endod J. 2022;48(1):202–18.
2. Alkahtani A, Al Khudhairi TD, Anil S. A comparative study of the debridement efficacy and apical extrusion of dynamic and passive root canal irrigation systems. BMC Oral Health. 2014;14:12.
3. Habeeb MA. Comparative evaluation of debris and irrigation extruded apically using different design of needles and penetration depth - an *in vitro* study. Indian J Dent Res. 2023;34(3):266–9.
4. Karatas E, Ozsu D, Arslan H, Erdogan AS. Comparison of the effect of nonactivated self-adjusting file system, Vibringe, EndoVac, ultrasonic and needle irrigation on apical extrusion of debris. Int Endod J. 2015;48(4):317–22.
5. Silva PB, Krolow AM, Pilownic KJ, Casarin RP, Lima RK, Leonardo Rde T, et al. Apical extrusion of debris and irrigants using different irrigation needles. Braz Dent J. 2016;27(2):192–5.
6. Baasch A, Campello AF, Rodrigues RCV, Alves FRF, Voigt DD, Mdala I, et al. Effects of the irrigation needle design on root canal disinfection and cleaning. J Endod. 2024;50(10):1463–71.
7. Dai Y, Wang S, Gao J, Liu Q, Xiong Z, Gao Y. The effects of aperture position and length in side-vented needles on root canal irrigation: a computational fluid dynamics study. Comput Biol Med. 2024;179:108940.
8. Loroño G, Zaldívar JMR, Arias A, Dorado S, Jimenez-Octavio JR. Influence of needle design and irrigation depth in the presence of vapor lock: a computational fluid dynamics analysis in human oval roots with apical ramification. Int J Numer Methods Biomed Eng. 2023;39(8):e3742.
9. Marques JA, Falacho RI, Santos JM, Ramos JC, Palma PJ. Effects of endodontic irrigation solutions on structural, chemical, and mechanical properties of coronal dentin: a scoping review. J Esthetic Restor Dent Off Publicat Am Acad Esthetic Dent. 2024;36(4):606–19.
10. Silva EJ, Carapiá MF, Lopes RM, Belladonna FG, Senna PM, Souza EM, et al. Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. Int Endod J. 2016;49(7):700–5.
11. Baasch A, Campello AF, Rodrigues RCV, Alves FRF, Voigt DD, Mdala I, et al. Effects of the irrigation needle design on root canal disinfection and cleaning. J Endod. 2024;50(10):1463–71.
12. Park E, Shen Y, Khakpour M, Haapasalo M. Apical pressure and extent of irrigant flow beyond the needle tip during positive-pressure irrigation in an *in vitro* root canal model. J Endod. 2013;39(4):511–5.
13. Uzunoglu E, Turker SA, Görduysus M. Effects of different rotary files combined with different irrigation needles on apically extruded debris. Braz Dent J. 2015;26(4):347–50.
14. Altundasar E, Nagas E, Uyanik O, Serper A. Debris and irrigant extrusion potential of 2 rotary systems and irrigation needles. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112(4):e31–5.
15. Boutsioukis C, Verhaagen B, Versluis M, Kastrinakis E, Wesselink PR, van der Sluis LW. Evaluation of irrigant flow in the root canal using different needle types by an unsteady computational fluid dynamics model. J Endod. 2010;36(5):875–9.
16. Tanalp J, Güngör T. Apical extrusion of debris: a literature review of an inherent occurrence during root canal treatment. Int Endod J. 2013. https://doi.org/10.1111/iej.12137.
17. Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing and canal master techniques. J Endod. 1991;17(6):275–9.
18. Chow TW. Mechanical effectiveness of root canal irrigation. J Endod. 1983;9(11):475–9.
19. Guerreiro-Tanomaru JM, Loiola LE, Morgental RD, Leonardo RT, Tanomaru-Filho M. Efficacy of four irrigation needles in cleaning the apical third of root canals. Braz Dent J. 2013;24(1):21–4.

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