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ORIGINAL ARTICLE

Quality aspects of *ex vivo* root canal treatments done by undergraduate dental students using four different endodontic treatment systems

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ABSTRACT

Objective: To evaluate factors associated with treatment quality of *ex vivo* root canal treatments performed by undergraduate dental students using different endodontic treatment systems.

Material and methods: Four students performed root canal treatment on 80 extracted human teeth using four endodontic treatment systems in designated treatment order following a Latin square design. Lateral seal and length of root canal fillings was radiographically assessed; for lateral seal, a graded visual scale was used. Treatment time was measured separately for access preparation, biomechanical root canal preparation, obturation and for the total procedure. Mishaps were registered. An ANOVA mirroring the Latin square design was performed.

Results: Use of machine-driven nickel-titanium systems resulted in overall better quality scores for lateral seal than use of the manual stainless-steel system. Among systems with machine-driven files, scores did not significantly differ. Use of machine-driven instruments resulted in shorter treatment time than manual instrumentation. Machine-driven systems with few files achieved shorter treatment times. With increasing number of treatments, root canal–filling quality increased, treatment time decreased; a learning curve was plotted. No root canal shaping file separated.

Conclusions: The use of endodontic treatment systems with machine-driven files led to higher quality lateral seal compared to the manual system. The three contemporary machine-driven systems delivered comparable results regarding quality of root canal fillings; they were safe to use and provided a more efficient workflow than the manual technique. Increasing experience had a positive impact on the quality of root canal fillings while treatment time decreased.

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Introduction

Technical root canal treatment quality, determined radiographically by adequate length and lateral seal, has been shown to have impact on the persistence of apical periodontitis [1,2]. Conventionally, cleaning and preparation of the root canal has been performed using stainless steel manual instruments. Root canal shaping instruments have evolved considerably during the last twenty years and it has been shown that the use of endodontic nickel-titanium instruments may have several advantages compared to stainless steel instruments by resulting in fewer procedural errors and complications [3]. Moreover, Ni–Ti instruments are more flexible than stainless steel instruments. The impact of different file systems on canal-shaping quality has been investigated in many *ex vivo* studies showing that the use of machine-driven Ni–Ti files leads to better canal shaping results than manual stainless-steel files [4–6]. Machine-driven files are designed to work in either continuous rotary movement or in a reciprocal movement. Contrary to marketing claims, choice of file generation, number of files or preparation movement have not yet been shown to be crucial for *in vitro* shaping [7,8] or clinical outcomes [9,10].

One much investigated parameter has been treatment time; it was shown that machine-driven instruments provide quicker shaping of the root canal compared to manual techniques [5,11,12]. However, the time spent preparing the root canal is only one part of the total endodontic treatment time, which can be divided into access preparation, biomechanical root canal preparation and filling time. It has not previously been estimated how much the decrease in preparation time would affect the total operating time.

It has been shown that inexperienced users benefit from using machine-driven NI–Ti file systems by acquiring more confidence in performing endodontic treatment [13] and an improved sense of security [11]. Nevertheless, not all dental schools have yet introduced the use of machine-driven Ni–Ti files into their pre-clinical curriculum [14]. Observations on inexperienced users like dental students are particularly interesting since students are not yet biased by clinical experience and marketing but have acquired a level of manual competencies [8].

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The effect of experience gained by repetitive endodontic treatment has previously been considered important to prevent file separation [15], while another study has suggested that experienced dentists may be more aggressive and this could result in more fractured instruments [16]. Several authors have found a correlation between experience and operation time [17–20]; however, the influence of experience on treatment quality has been only sparsely investigated.

The objective of the present study was to evaluate factors related to treatment quality of *ex vivo* root canal treatments performed by four undergraduate dental students using four different endodontic treatment systems and observing treatment time for individual endodontic treatment steps.

Materials and methods

Four fourth-year undergraduate dental students each performed 20 endodontic treatments using four different endodontic treatment systems. Each operator used each system in one session that included five teeth. The experiment was arranged in a Latin Square design in order to obtain balanced comparisons between treatment systems. A treatment order was assigned to each of the operators, ensuring that each operator used each system once at a different time during the experiment (Table 1).

Randomly selected, permanent, single-rooted, extracted human teeth were examined by bucco-lingual radiographs (GX 1,000, Gendex Corporation, Milwaukee, WI, 70 kV, 10 mA). Root-filled teeth and teeth with no radiographically visible root canal were excluded and replaced by teeth of the same tooth type. Thus, a total of 80 specimen was selected. Age of patients and reason for extraction was unknown. Most of the roots were straight, fewer than 5% were curved more than 10 degrees in either the mesio-distal or bucco-lingual plane or both planes. The teeth were fixated in 2×2 cm foam blocks and kept hydrated with 0.2% chlorhexidine. The teeth were sorted in tooth groups according to tooth type. Each tooth group was in turn distributed into four treatment groups representing four root canal treatment systems. Within treatment groups, the teeth were treated in random order. Among the 80 teeth, 74 had one canal. In six cases, a second canal was present; in these cases only the buccal canal was treated.

The investigated endodontic treatment systems included: K-flex stainless steel hand files and cold lateral compaction (KF) (Kerr Dental, Orange, CA), ProTaper Universal (PTU), ProTaper Next (PTN), and Wave One (WO) (Dentsply Sirona, Ballaigues, Switzerland). Before treatment, operators participated in a calibration session concerning the manuals of the four root canal treatment systems. During the experiment, operators did not exchange experiences about treatment systems.

Table 1. Latin square design: arrangement of operators and endodontic treatment systems.

	1st	2nd	3rd	4th
Operator 1	PTN	WO	KF	PTU
Operator 2	WO	KF	PTU	PTN
Operator 3	KF	PTU	PTN	WO
Operator 4	PTU	PTN	WO	KF

KF: K-Flex; PTN: ProTaper Next; PTU: ProTaper Universal; WO: WaveOne.

Root canal preparation and root canal filling

An endodontic access cavity was prepared. The root canal length was established by visibility of the tip of a K-Flex file at the apex. The length of the file was measured, and the working length was set to be 1 mm shorter.

With K-flex files, balanced force technique was used [21]. The size of the final file was defined to be two ISO sizes larger than the first file meeting apical resistance. With the machine-driven instruments, the manufacturer's manuals were followed. A new set of files was used for every session consisting of five teeth.

The root canal was irrigated using 3 ml NaOCl 1% after each instrument when KF, PTU and PTN were used. When WO was used, the canal was irrigated for each 2–3 mm the file advanced in apical direction. When canal preparation was finished, smear layer was removed using EDTA 10%, which was left in the root canal for one minute. The canal was dried with paper points and filled with gutta-percha and AH Plus sealer (Dentsply Sirona, Ballaigues, Switzerland), using cold lateral compaction for KF and single-point technique for PTU, PTN and WO as recommended by the manufacturer; surplus gutta-percha in the crown of the tooth was removed with a heated instrument.

Instrument fractures and other mishaps were recorded.

Evaluation of root canal fillings

When all treatments were finished, two digital radiographs of each tooth (GX 1,000, Gendex Corporation, Milwaukee, WI, 70 kV, 10 mA) were taken in bucco-lingual and mesio-distal direction. Quality of root canal fillings was assessed by length and quality of lateral seal. Lateral seal was scored in one of four categories by direct comparison to the reference (Figure 1, modified from Jordal et al. [22]). Length was rated as short, adequate or long (Table 2).

Before scoring radiographs from the survey, six observers were calibrated by scoring 20 teeth that were not included in the study together. Two observers were experienced dentists, four observers were undergraduate dental students. Observers were blinded to operator and system. All radiographs of 80 teeth, in two directions, were scored twice in random order, leading to 24 ratings of length and density per tooth and 480 ratings per endodontic treatment system.

Operation time

The time used on endodontic treatment was registered for each tooth. The time period from the start of access cavity preparation until length determination was defined as *access* time. *Preparation* time included shaping of the root canal, NaOCl irrigation, EDTA application and drying the canal. Root canal *filling* time started with fitting the masterpoint and ended with the removal of the excess gutta-percha. These operation times added up to a *total* operating time.

Data treatment

The distribution of ratings of quality by length and by lateral seal was obtained for each endodontic treatment system and for each of the four sessions. For each quality parameter, the scoring was dichotomized as adequate or inadequate (Table 2) and the proportion of adequate ratings (out of 24) were computed for each tooth. These proportions were evaluated by the analysis of variance, which reflected the Latin Square design [23], allowing an assessment of the importance of treatment system, operator and session order on the quality of the root canal filling.

The three components of operation time and the total operation time were also analysed by this type analysis of variance. Moreover, the proportion of time spent on each of the three components was assessed similarly. Stata version 13 was used for all statistical analyses (StataCorp 2013, College Station, TX).

Results

Lateral seal and length

For lateral seal, manual stainless-steel instrumentation gave significantly smaller proportions of ratings as adequate compared to those performed with a machine-driven nickel-titanium system ($p = .016$, Figure 2). Poorest rating of lateral seal was observed with KF (47% adequate) and best rating was observed using PTU (74% adequate). Among the three treatment systems with machine-driven files, no statistically significant difference in the quality of lateral seal of the root canal fillings was seen ($p = .713$). For the length of the root canal fillings, the proportion of ratings scored as adequate was not significantly associated with the used treatment system ($p = .872$).

The proportion of adequate ratings of the lateral seal of the root canal fillings increased with session number (Figure 3). The improvement of lateral seal quality was statistically significant ($p = .010$). Moreover, with increasing experience, the proportion of adequate ratings of the length of the root canal filling increased significantly ($p = .026$). In the first session consisting of five teeth, the average proportion of ratings as adequate length was 33%, while in the final session of five teeth, the average proportion of ratings for adequate root filling length was 53%.

During preparation of the canals, no instruments separated. Two separated lentulo spiral fillers were observed in the first session of one of the operators while filling the canal.

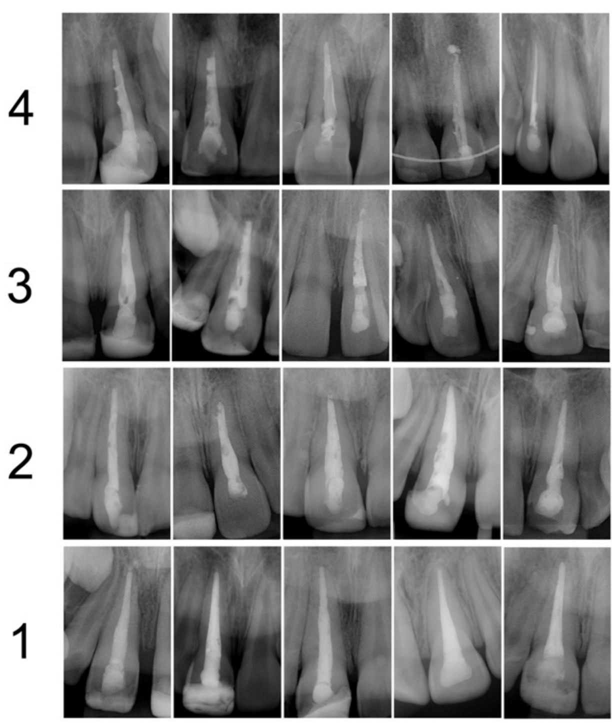

Figure 1. Scoring system for lateral seal of root canal fillings (modified from Jordal et al. [22]).

Table 2. Radiographic assessment parameters.

Quality Parameters	Categories and thresholds	
Root-filling length	Short	>2 mm from radiographic apex
	Adequate	0–2 mm from radiographic apex
	Long	material beyond radiographic apex
Root-filling density[a]	Adequate	Score 1,2
	Inadequate	Score 3,4

[a]scored by comparison to the reference (Figure 1, modified from Jordal et al. [22]).

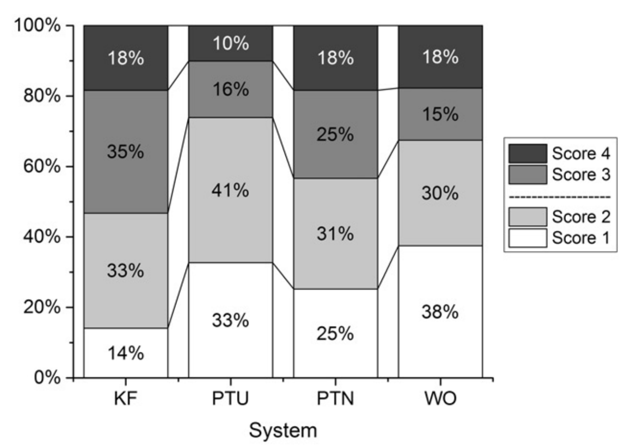

Figure 2. Quality of lateral seal of root canal fillings by endodontic treatment system.

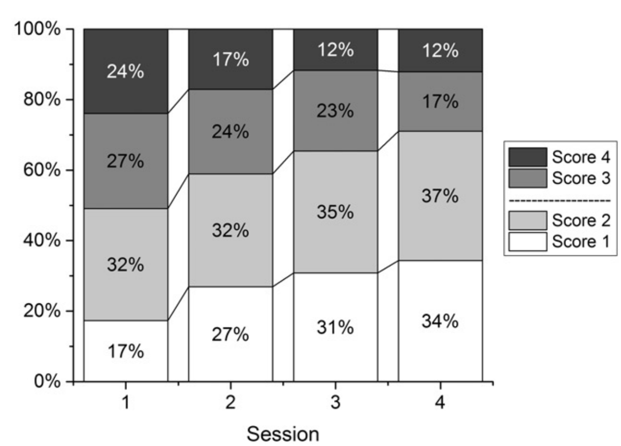

Figure 3. Quality of lateral seal of root canal fillings by session.

Operation time

Significant differences between the four systems were found regarding root canal *preparation* time and *total* operation times ($p < .0001$, Table 3). Treatment systems with machine-driven files were significantly quicker than the manual system regarding *preparation* ($p < .0001$), root canal *filling* ($p = .018$) and *total* times ($p < .0001$). Furthermore, *preparation* ($p = .001$) and *total* ($p = .01$) times differed significantly among the machine-driven systems; systems using fewer files were less time-consuming.

The *total* time decreased with increasing number of sessions ($p < .0001$) (Figure 4). The reduction of the *total* treatment time was primarily due to shorter time spent on *preparing* ($p = .05$) and on *filling* ($p < .0001$) the canal. The reduction in the operation time was primarily seen from the first to the second session. Further reduction in session three and four was limited.

Discussion

In an effort to assess quality and efficacy aspects of different endodontic treatment systems, we performed an experimental study planned as a 4 × 4 Latin square design (Table 1). The design ensured that simple averages gave unbiased estimates that could be compared by an analysis of variance. A Latin square design may be considered as a generalization of a simple cross-over design. The latter has been used in several experimental studies also investigating file systems used by inexperienced operators [8,12]; other investigators have used a designated sequence of endodontic procedures [24] that could, however, be confounded by learning.

Previously, either artificial root canals or extracted teeth were used to assess the performance of endodontic treatment systems. Artificial root canals permit standardization of length and curvature of the treated root canals. However, resin hardness and abrasion may be different to dentin properties [25,26]. Thus, natural teeth were used in the present study to investigate performance and efficacy of treatment systems on dentin. Efforts were made to ensure comparable results despite possible dissimilarities in natural morphology. One canal per tooth was treated to ensure comparable treatment times. Only single-rooted teeth with radiographically visible canals were included and different tooth groups were in turn allocated into the different treatment groups.

Technical quality of the lateral seal of the root canal fillings was assessed by direct comparison of digital radiographs to a four-grade visual scale (Figure 1, modified from Jordal et al. [22]). The advantage of this method is that it covers both density and taper to characterize lateral seal and includes information about absence or presence of voids. Previously, quality measures have been described independently and dichotomously by presence or absence of voids or low density without any visual references [27]. Beyond the bucco-lingual view, a mesio-distal radiograph was taken to reduce underestimation of voids [28].

In the present study, radiographic quality of lateral seal was significantly higher when machine-driven nickel-titanium instruments were used, compared to stainless steel manual instruments. This is in accordance with previous investigations [27,29]. Among the three treatment systems with machine-driven files in the present study, no superiority of one system regarding lateral seal or length of the root canal filling was observed, which is in agreement with findings from Marending et al. [8]. One investigation did find improved *working* length preservation comparing machine-driven nickel-titanium instruments to manual preparation [12]; however, canals have not been filled and sealed and canal curvature may have contributed to length loss.

In the present investigation, the students had been introduced to ProTaper Universal previously. This had, however, no observable effect, since lateral seal outcomes among endodontic systems with machine-driven files did not significantly differ. With increasing number of sessions, length and lateral seal (Figure 3) improved significantly, indicating a learning curve for the full process of *ex vivo* root canal treatments. Previous studies have found slight influence of previous experience on treatment quality but not to the level of significance [12,24] and focusing only on one aspect of root canal treatment. A 'law of practice' has been described in psychology, indicating that learning might follow a function [30]. The relationship between practice and learning shows substantial improvement in the beginning and only slight subsequent improvement ending at a plateau phase [31].

Table 3. Treatment time by system.

	Total time		Access time		Preparation time		Filling time	
System	Mean[a]	SEM[b]	Mean[a]	SEM[b]	Mean[a]	SEM[b]	Mean[a]	SEM[b]
KF	18.26	0.92	2.86	0.40	10.89	0.70	4.50	0.30
PTU	15.35	0.92	2.09	0.40	9.43	0.70	3.83	0.30
PTN	13.11	0.92	2.27	0.40	7.25	0.70	3.60	0.30
WO	11.40	0.92	2.22	0.40	5.64	0.70	3.54	0.30
No difference[c]	<0.0001		0.531		<0.0001		0.107	
Hand vs. Motor[c]	<0.0001		0.145		<0.0001		0.018	
Motor vs. Motor[c]	0.01		0.947		0.001		0.769	

[a]Corrected for the effects of session and operator.
[b]Based on the residual variance in the analysis of variance.
[c]*p* values from analysis of variance.

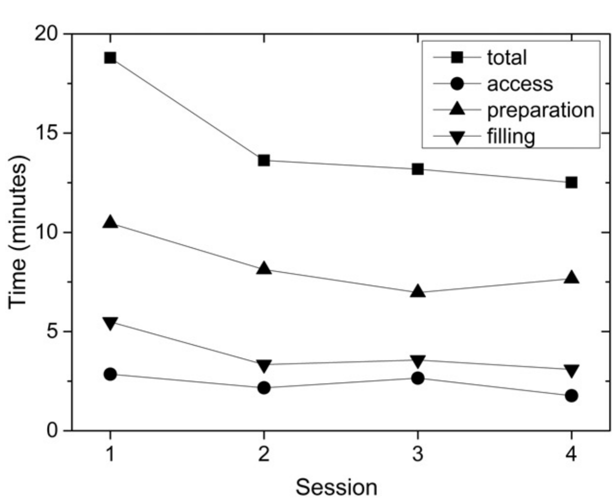

Figure 4. Learning curve: Time spent on treatment by session.

However, we have to be careful here because the experiment setting of *ex vivo* root canal treatment was new to the operators as well, which may have influenced the learning curve of these particular students. Our findings can therefore not be applied to a total number of treatments needed to reach the plateau phase of a learning curve.

In the present investigation, no shaping file was separated. However, two lentulo spiral fillers were separated by one operator. Other authors have suggested that separation of files may be rather dependent on individual operator factors than on experience [11].

In the present investigation, PTU was observed to be the slowest of the treatment systems with machine-driven files (Table 3), indicating no effect of previous familiarity on treatment time. In accordance with other investigations, we found machine-driven systems to achieve significantly shorter root canal *preparation* times than manual systems [5,11,12]. In addition to root canal *preparation* time, the present study assessed *access* cavity preparation, root canal *filling* and *total* time to evaluate the relative time of each step and hence increase comparability to the clinical situation. Use of machine-driven systems demonstrated a more efficient overall workflow with shorter *filling* and *total* times. Among the machine-driven file systems, systems with fewer files achieved significantly shorter *preparation* times (Table 3). This was also found by Marending et al. [8] and Bürklein et al. [7]. Only one study found a system with fewer files to be slower [32], this study, however, included only one tooth prepared with each system.

A range of studies observed a decrease in preparation time with increasing experience using single-file reciprocating systems [17–19] and a short learning period [19]. Inverse proportionality of experience and root canal *preparation* time has been described for PTU [20]. In the present study, the most distinct reduction of treatment time occurred from the first to the second session. After that, treatment time only changed slightly. Learning curves for treatment time dependent on experience were plotted (Figure 4). Reduction of the *total* treatment time was primarily due to less time spent on *preparing* and *filling* the canal.

A limitation of the present study is that there only have been investigated four undergraduate dental students. Future studies would benefit from investigating more individuals and should identify the impact of experience on clinical competency. The performance of contemporary endodontic treatment systems and their impact on clinical outcome should be further investigated.

Conclusions

Quality aspects of *ex vivo* root canal treatments performed by students were assessed. Lateral seal was of higher quality when a machine-driven nickel-titanium system was used instead of stainless steel files. Among the three endodontic treatment systems with machine-driven files, quality did not significantly differ. Machine-driven systems with fewer files were more efficient. Lateral seal and length of root canal fillings improved with increasing experience, whereas treatment time decreased.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Petersson K, Fransson H, Wolf E, et al. Twenty-year follow-up of root filled teeth in a Swedish population receiving high-cost dental care. Int Endod J. 2016;49:636–645.

[2] Kirkevang LL, Vaeth M, Wenzel A. Ten-year follow-up of root filled teeth: a radiographic study of a Danish population. Int Endod J. 2014;47:980–988.

[3] Pettiette MT, Metzger Z, Phillips C, et al. Endodontic complications of root canal therapy performed by dental students with stainless-steel K-files and nickel-titanium hand files. J Endod. 1999;25:230–234.

[4] Dafalla AA, Abubakr NH, Ibrahim YE. An in vitro comparison of root canal system prepared with either hand or rotary instruments. Iran Endod J. 2010;5:167–173.

[5] Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni-Ti rotary GT files versus traditional instruments in canals shaped by novice operators. Int Endod J. 2001;34:476–484.

[6] Peru M, Peru C, Mannocci F, et al. Hand and nickel-titanium root canal instrumentation performed by dental students: a micro-computed tomographic study. Eur J Dent Educ. 2006;10:52–59.

[7] Bürklein S, Hinschitza K, Dammaschke T, et al. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J. 2012;45:449–461.

[8] Marending M, Biel P, Attin T, et al. Comparison of two contemporary rotary systems in a pre-clinical student course setting. Int Endod J. 2016;49:591–598.

[9] Peters OA, Barbakow F, Peters CI. An analysis of endodontic treatment with three nickel-titanium rotary root canal preparation techniques. Int Endod J. 2004;37:849–859.

[10] Schäfer E, Bürklein S. Impact of nickel-titanium instrumentation of the root canal on clinical outcomes: a focused review. Odontology. 2012;100:130–136.

[11] Sonntag D, Delschen S, Stachniss V. Root-canal shaping with manual and rotary Ni-Ti files performed by students. Int Endod J. 2003;36:715–723.

[12] Sonntag D, Guntermann A, Kim SK, et al. Root canal shaping with manual stainless steel files and rotary Ni-Ti files performed by students. Int Endod J. 2003;36:246–255.

[13] Martins RC, Seijo MO, Ferreira EF, et al. Dental students' perceptions about the endodontic treatments performed using NiTi rotary instruments and hand stainless steel files. Braz Dent J. 2012;23:729–736.

[14] Sonntag D, Barwald R, Hülsmann M, et al. Pre-clinical endodontics: a survey amongst German dental schools. Int Endod J. 2008;41:863–868.

[15] Mandel E, Adib-Yazdi M, Benhamou LM, et al. Rotary Ni-Ti profile systems for preparing curved canals in resin blocks: influence of operator on instrument breakage. Int Endod J. 1999;32:436–443.

[16] Baumann MA, Roth A. Effect of experience on quality of canal preparation with rotary nickel-titanium files. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999;88:714–718.

[17] Generali L, Righi E, Todesca MV, et al. Canal shaping with WaveOne reciprocating files: influence of operator experience on instrument breakage and canal preparation time. Odontology. 2014;102:217–222.

[18] Muñoz E, Forner L, Llena C. Influence of operator's experience on root canal shaping ability with a rotary nickel-titanium single-file reciprocating motion system. J Endod. 2014;40:547–550.

[19] Yang Y, Shen Y, Ma J, et al. A micro-computed tomographic assessment of the influence of operator's experience on the quality of WaveOne instrumentation. J Endod. 2016;42:1258–1262.

[20] Mesgouez C, Rilliard F, Matossian L, et al. Influence of operator experience on canal preparation time when using the rotary Ni-Ti ProFile system in simulated curved canals. Int Endod J. 2003;36:161–165.

[21] Carrotte P. Endodontics: part 7. Preparing the root canal. Br Dent J. 2004;197:603–613.

[22] Jordal K, Valen A, Ørstavik D. Periapical status of root-filled teeth in Norwegian children and adolescents. Acta Odontol Scand. 2014;72:801–805.

[23] Armitage P, Berry G, Mathews JNS. Chapter 9.4, Latin squares. In: Statistical methods in medical research. Oxford (UK): Blackwell; 2002. p. 257–261.

[24] Gound TG, Sather JP, Kong TS, et al. Graduating dental students' ability to produce quality root canal fillings using single- or multiple-cone obturation techniques. J Dent Educ. 2009;73:696–705.

[25] Lim KC, Webber J. The validity of simulated root canals for the investigation of the prepared root canal shape. Int Endod J. 1985;18:240–246.

[26] Hülsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. Endodontic Topics. 2005;10:30–76.

[27] Roman-Richon S, Faus-Matoses V, Alegre-Domingo T, et al. Radiographic technical quality of root canal treatment performed ex vivo by dental students at Valencia University medical and dental school, Spain. Med Oral Patol Oral Cir Bucal. 2014;19:e93–e97.

[28] Møller L, Wenzel A, Wegge-Larsen AM, et al. Comparison of images from digital intraoral receptors and cone beam computed tomography scanning for detection of voids in root canal fillings: an in vitro study using micro-computed tomography as validation. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013;115:810–818.

[29] Abu-Tahun I, Al-Rabab'ah MA, Hammad M, et al. Technical quality of root canal treatment of posterior teeth after rotary or hand preparation by fifth year undergraduate students, the University of Jordan. Aust Endod J. 2014;40:123–130.

[30] Ritter FE, Schooler LJ. Learning curve, The. In: Smelser, NJ, Baltes PB, editors. International encyclopedia of the social & behavioral sciences. Oxford (UK): Pergamon; 2001. p. 8602–8605.

[31] Chambers D. Learning curves: what do dental students learn from repeated practice of clinical procedures? J Dent Educ. 2012; 76:291–302.

[32] Gekelman D, Ramamurthy R, Mirfarsi S, et al. Rotary nickel-titanium GT and ProTaper files for root canal shaping by novice operators: a radiographic and micro-computed tomography evaluation. J Endod. 2009;35:1584–1588.