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EVALUATION OF THE ACCURACY OF THE NITI K-FILES AND GUTTA-PERCHA CONES IN GAUGING THE APICAL FORAMEN USING THE SCANNING ELECTRON MICROSCOPE: AN IN VITRO STUDY

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Objectives: The aim of this study was to compare the accuracy of apical gauging using NiTi K-files and gutta-percha cones and determine the level of agreement between the two methods using a Scanning Electron Microscope (SEM).

Methods: 75 circular and straight canals of mandibular first premolars were used. Canals were shaped using the R-Motion system (RM; FKG Dentaire, La Chaux-de-Fonds, Switzerland) and gauged using NiTi K-Files and gutta-percha cones matching the shaping instrument. Diameters measured on SEM images were used as the reference standard.

Results: There was a statistically significant difference in the prediction of apical diameter by gauging with both NiTi K-Files ($P<0.001$) and with gutta-percha cones ($P<0.001$) compared with the measurement of the diameter with the SEM. However, there were no significant differences between both gauging methods.

Conclusions: NiTi K-Files and gutta-percha cones have similar accuracy but are not accurate in gauging the apical foramen.

Key words: Apical gauging, apical diameter, scanning electron microscopy, Gutta-Percha Cones, NiTi K-Files

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The authors declare no conflicts of interest.

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ÉVALUATION DE LA PRÉCISION DES LIMES K EN NITI ET DES CONES DE GUTTA-PERCHA POUR LE JAUGEAGE DU FORAMEN APICAL AVEC MICROSCOPIE ÉLECTRONIQUE À BALAYAGE: UNE ÉTUDE IN VITRO

Objectifs: Cette étude visait à comparer la précision de jaugeage du foramen apical avec des limes-K en NiTi et des cônes de gutta-percha, ainsi que leur niveau d'accord grâce à un microscope électronique à balayage(MEB).

Méthodes: 75 canaux circulaires et droits de premières prémolaires mandibulaires ont été utilisés. Ils ont été mis en forme avec le système R-Motion(RM; FKG Dentaire, La Chaux-de-Fonds, Suisse) et jaugés avec des limes-K en NiTi et des cônes de gutta-percha associés à l'instrument utilisé. Les diamètres mesurés au MEB étaient la référence.

Résultats: Une différence significative a été observée dans la prédiction du diamètre par jaugeage avec les limes-K en NiTi(P<0.001) et les cônes de gutta-percha(P<0.001) comparé aux mesures du MEB. Il n'y a pas de différence significative entre les deux méthodes de jaugeage.

Conclusion: Bien que les deux méthodes aient une précision similaire, aucune d'entre elle n'est assez précise pour estimer le diamètre apical.

Mots clés: Jaugeage, Diamètre Apical, Microscopie Électronique A Balayage, Cônes De Gutta-Percha, Limes-K En NiTi

Introduction

Root canal obturation is a crucial step in endodontic treatment, as insufficient sealing may lead to treatment failure [1]. To achieve a hermetic, three-dimensional seal, apical gauging should be performed and filling material, such as gutta-percha (GP), should be closely adapted to the root canal walls [2]. Apical gauging involves measuring the terminal diameter of a canal [3]. To date, nickel titanium (NiTi) K-files have been used for gauging because they are flexible and have a 0.02mm/mm taper along their length. This requires only a 0.04mm/mm taper in root canal preparation. While stainless steel K-files can gauge accurately, they may give inaccurate results, especially in curved canals, due to their relative inflexibility [4]. The technique of apical gauging, described by S. Buchanan in 1989, involves starting with a #20 NiTi K-file and gradually using larger instruments to determine the size that reaches the terminus without passing through it, and stepping back from this position [4]. However, the accuracy of endodontic instruments used for gauging is questionable as these files may not have the exact shape of the foramen, as the lumen of instrumented canals can be larger than the designated file size [5].

Today, GP cones that match the taper and diameter of canals prepared with NiTi rotary files are commonly offered with each system. These matching cones ensure a high volume of GP in the canal and minimal sealer, as the sealer is not dimensionally stable [6].

The quality of obturation depends on canal preparation and instruments used, so minimizing instrumentation errors is crucial. In 2020, a new reciprocating single-file preparation system, the R-Motion system (RM) by FKG Dentaire, was launched. This system is minimally invasive and has a reduced taper compared to other reciprocating instruments. The size 25 instrument has a 0.06 taper, a rounded triangular cross-section with sharp cutting edges, an inactive tip, and is heat treated [7]. The system also includes matching GP cones to match the taper and diameter of the shaping instrument used. There may be discrepancy between the file size used for shaping and the actual diameter of the canal and the correlation between the file, cone, and real diameter of the foramen is unknown. The purpose of this study is to compare the accuracy and reliability of apical gauging using NiTi K-files and GP cones, by measuring the foramina diameter with a Scanning Electron Microscope (SEM) as the reference standard. The aim is to determine the level of agreement between the two gauging methods and address the lack of information about the relationship between the file size, cone size, and actual foramen diameter. The null hypothesis states that there is no significant difference in the accuracy between NiTi K-files and Gutta-Percha cones in gauging the apical foramen

Materials and Methods

Sample selection

This study was approved by the Ethical Committee of Saint Joseph University of Beirut, Beirut, Lebanon (USJ-2021-7). A power analysis was conducted considering a medium size effect of 0.5 (alpha= 5%, 95% power) and a sample size of 54 canals minimum was calculated.

85 recently extracted non-carious human mandibular first premolars were collected and stored in formalin (5%). These teeth were extracted for orthodontic reasons. Teeth were stabilized in a customized polyvinyl siloxane impression material jig and radiographed in buccolingual and mesiodistal projections to verify the presence of one single and straight root canal (curvature < 5°) and to make sure the canal is circular-shaped [8]. The space corresponding to the root canal lumen was measured 5 mm from the apex. The canals were considered circular-shaped when the buccolingual diameter constituted less than 2.5 times the mesiodistal diameter [9]. Exclusion criteria included: teeth presenting a damaged crown, posts or indirect restorations, cracks, previous endodontic treatment, anatomical complexities, resorptions, or calcifications. Canals in which foraminal patency was not achieved were also excluded. Teeth were stored in 0.9% saline solution at room temperature after being cleaned and disinfected [10].

Initial SEM

A reference point was marked on each root apex using nail varnish to keep the plane of the foramen in the same position for accurate post-instrumentation images. The samples were dehydrated and sputtered with gold for the initial SEM (SEM MIRA Tescan 3) examination [11]. Apices were examined under 200 x magnification and 20.00 Kv. Root canals in which the Apical Foramen (AF) diameter was greater than 200 μm were excluded [10]. 75 canals fulfilled the criteria and were thus introduced in this study.

Root canal preparation

The gold was gently removed with a soft brush. Standard access cavities were made and the nearest cusp tip to each canal was flattened to have a reproducible reference point. Canals were irrigated with 2 mL of 5.25% sodium hypochlorite and negotiated using a size 08 K-file (Dentsply Maillefer, Ballaigues, Switzerland) until the tip was just visible and tangent to the apical foramen under 16x magnification using a dental operating microscope Leica M320 (Wetzlar, Germany) [3], [12] nonlanded (ProFile Vortex. The rubber stop was then carefully adjusted to the reference point to measure the working length (WL), and the distance between the file tip and the rubber stop was measured using an endodontic ruler (R1, Woodpecker) under 5x magnification [11].

The root canal instrumentation protocol was performed according to the manufacturer's recommendations. A single operator performed the instrumentation of all the canals. The R-Motion Glider (15/.03) was used with the X-Smart Plus motor (XSM, Dentsply Maillefer) in Reciproc ALL mode to the WL with a slight pressure making in-and-out movements with an amplitude of 3 to 4 mm. After glidepath, the canals were instrumented using the R-motion 25 (25/.06) in the same motion. After every in-and-out pecking movements, the instrument was cleaned with a gauze. Patency was verified using a size 10 K-file (Dentsply Maillefer, Switzerland) introduced 0.5 mm beyond the foramen. After each usage of the file, canals were irrigated with 2 mL of 2.5% sodium hypochlorite using an IrriFlex needle 30/.04 (Produits Dentaires, Vevey, Switzerland) and the instrument was then reintroduced in the canal. After preparation of the cervical and middle thirds, WL was determined again using a #10 K-File with a rubber stop and an endodontic ruler (R1, Woodpecker) under magnification (× 16) using Leica M320 dental microscope (Wetzlar, Germany). The shaping was then done till WL. A total volume of 20 mL of irrigation was used in each canal. A final irrigation protocol included 5 mL of EDTA 17% (Vista) for 1 min followed by 5 mL of sodium hypochlorite 5.25% for 1 min and 5 mL of distilled water. Each instrument was used for the preparation of 3 canals.

Manual gauging

Instrumented canals were gauged manually using K Nitiflex files (Dentsply, Maillefer, Switzerland): Starting with a #25 NiTi K-file, progressively larger files were passively introduced into the canal until the operator felt the largest to bind at the WL and the next larger one not to reach that position. The operator was an experienced specialist in endodontics and was blinded to the other methods during these procedures [13]. Gauging was accomplished when files of increasing diameter reach progressively shorter lengths. A control buccolingual and mesiodistal radiograph using the Carestream CS 2100 machine (Atlanta, Georgia) validated the position of the file [2].

Gauging using a GP cone

After completion of the preparation procedure, a #25/.06 GP cone (FKG Dentaire, Le Crêt-du-Locle, Switzerland) was inserted to the WL to verify the adaptation of the cone. The cone had to reach the WL and not advance further and the cone fitness was confirmed when the tug-back sensation was felt [2].

If the tug-back sensation was not adequate when the #25/.06 GP cone (FKG Dentaire, Le Crêt-du-Locle, Switzerland) reached the WL, a #30/.04 GP cone (FKG Dentaire, Le Crêt-du-Locle, Switzerland) was inserted to the WL of the canal and the tug back sensation was evaluated.

A control buccolingual and mesiodistal radiograph using the Carestream CS 2100 machine (Atlanta, Georgia) validated the position of the GP cone [2].

Final SEM

Following root canal preparation, teeth were scanned again using the scanning electron miscroscope and by adopting the same procedure as previously described. To correctly visualize the apex and position it through the same angle, the previously manufactured jig was used. A total of 150 photomicrographs were obtained for the 75 specimens, consisting of 1 preoperative image and 1 postinstrumentation image for each canal [11] (Figure 1).

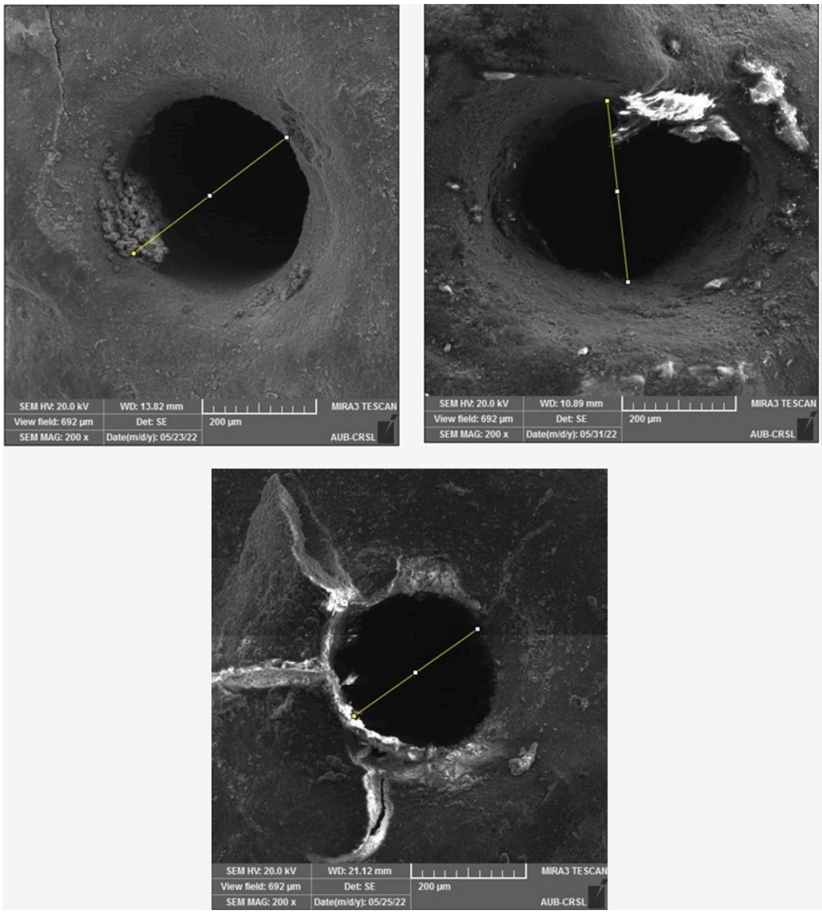

Figure 1. SEM images with the measurement of the apical foramen diameter

Analysis of the SEM images

Using ImageJ software, a measure of the minor diameter of the foramen was done by an experienced evaluator. An experienced evaluator, who was blinded to the group assignment of the specimens manually traced the perimeter of the apical foramen. Using ImageJ, the area, circularity and Feret diameters of the foramens were calculated for both preoperative and postinstrumentation microphotographs. A circularity value close to 0.0 represents a straight line whereas a value of 1.0 suggests that the apical foramen is a perfect circle [14]. The maximum and minimum feret diameters were calculated by finding, respectively, the longest and shortest distances between 2 parallel lines that are tangent to the foramen's shape. The ferret diameter ratio was found by dividing the greatest value by the smallest one [11, 12, 15] Munich, Germany.

The results of the diameters obtained by manual gauging, gauging with GP and the diameters obtained by the SEM were compared.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA) with a significance level set at 5%. Descriptive statistics for quantitative and qualitative variables were presented as means ± standard deviations (SD) and frequencies/percentages respectively. The normal distribution of quantitative variables was assessed using Kolmogorov-Smirnov tests. Considering measurements of the true diameters of the roots' foramina using the scanning electron microscope (SEM) as the gold standard, the accuracy and criterion validity of the measurements predicted from the manual gauging method using hand files and those predicted from the same method but with GP cones were determined with paired-samples T tests and with intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals using a single-measurement, absolute agreement, and two-way mixed effects model. The level of agreement between both gauging methods was assessed using the ICC as well; and the accuracy between both gauging methods was assessed using the Wilcoxon matched-pair signed-rank test. Intraclass correlation coefficient estimates were interpreted as follows: values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.9, are indicative of poor, moderate, good, and excellent validity/agreement, respectively.

the hand file gauging method was 0.016 ± 0.011 (range: 0 – 0.06). Figure 2 shows the Bland-Altman plot agreement analysis between SEM and apical gauging with hand files method, displaying the mean bias = 0.013, and limits of agreement (lower limit = -0.016, upper limit = 0.042). On average, the hand file gauging method measures foramina diameters to be 0.013 millimeters narrower than the true diameters, and 95% of the differences in diameter between the hand file gauging method and the true values on SEM are expected to fall in the range of -0.016 millimeters and 0.042 millimeters (Figure 2).

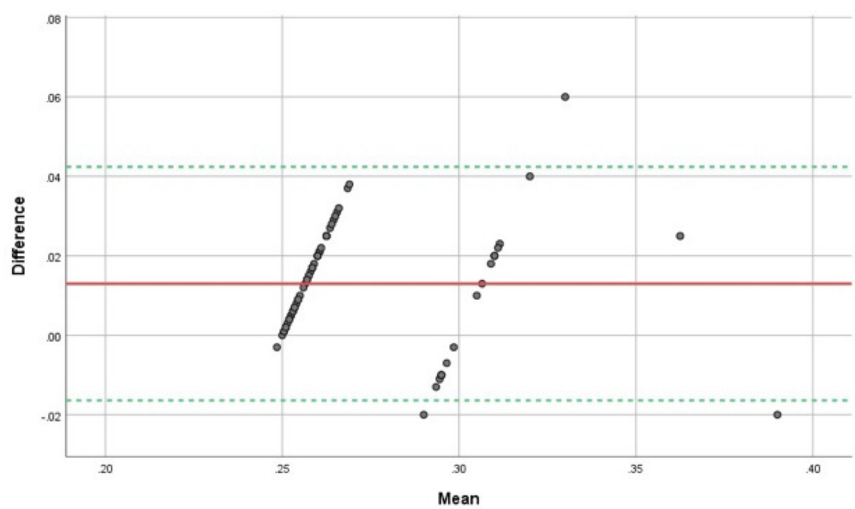

Figure 2. Bland-Altman plot for hand file apical gauging method agreement analysis with the SEM measurements (n = 75). Limits of Agreement are shown as dotted green lines and mean bias as solid red line.

Results

In total, 75 root canals met the inclusion criteria and were included in the analysis. Results of the comparison of means between measurements done on the SEM and those predicted from the apical gauging method using hand files are shown in Table 1. The mean of the true foramina diameters measured on the SEM was significantly greater than the mean of diameters predicted from the apical gauging method with hand files (P < 0.001*). The mean of the absolute error for

Table 1 also shows results of the comparison of means between measurements performed on the SEM and those predicted from the apical gauging method using GP. Diameters predicted from the apical gauging with GP were significantly lower than the true diameters measured on the SEM (P < 0.001*). The mean of the absolute error for the GP gauging method was 0.016 ± 0.010 (range: 0 – 0.05). Figure 3 shows the Bland-Altman plot agreement analysis between SEM and apical gauging with GP method, displaying the mean bias = 0.011, and

Table 1. Comparisons between SEM and hand file apical gauging method, between SEM and GP gauging method, and between both apical gauging methods

	Diameter (mm) *Mean ± SD*	Comparison	Difference (mm) *Mean ± SD*	95% CI *Lower Bound*	95% CI *Upper Bound*	*p*-value
SEM	0.280 ± 0.029	**SEM – Hand file gauging**	0.013 ± 0.015	0.010	0.017	<0.001*
Apical gauging with hand files	0.267 ± 0.029	**SEM – GP gauging**	0.011 ± 0.015	0.007	0.015	<0.001*
Apical gauging with GP	0.269 ± 0.028	**Hand file – GP gauging**	0.002 ± 0.013	-0.001	0.005	0.180

SD = standard deviation; 95% CI = 95% confidence interval; * Signifiant if p < 0.05

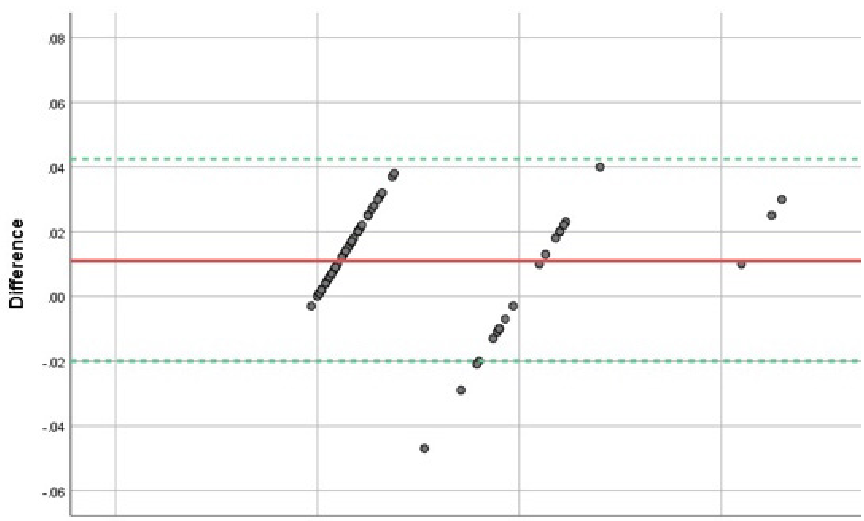

Figure 3. Bland-Altman plot for GP apical gauging method agreement analysis with the SEM measurements (n = 75). Limits of Agreement are shown as dotted green lines and mean bias as solid red line.

Table 2. Intraclass correlation coefficients (ICC) showing validity of the gauging methods compared to the true values measured on the SEM, and the level of agreement between both apical gauging methods

	ICC	**95% CI** *Lower Bound*	**95% CI** *Upper Bound*	***p*-value**
SEM – Hand files gauging	0.795	0.335	0.915	<0.001*
SEM – GP gauging	0.791	0.504	0.897	<0.001*
Hand files – GP	0.892	0.831	0.932	<0.001*

95% CI = 95% confidence interval; *Signifiant if p < 0.05

limits of agreement (lower limit = -0.02, upper limit = 0.042). On average, the GP gauging method measures foramina diameters to be 0.011 millimeters narrower than the true diameters, and 95% of the differences in diameter are expected to fall in the range of -0.02 millimeters and 0.042 millimeters (Figure 3).

The comparison of predicted diameters between apical gauging with hand files and apical gauging with GP are displayed in Table 1 as well. The difference found between both gauging methods was not statistically significant (P = 0.180) which indicated good accuracy of the apical gauging methods using the GP when the apical gauging with hand files was considered as the reference. The mean of the absolute error for the GP gauging method in reference to the hand file gauging method was 0.004 ± 0.013 (range: 0 – 0.05).

Results of validity of both apical gauging methods are shown in Table 2. The hand file apical gauging method showed poor to excellent validity (0.335 – 0.915), while the GP gauging method showed moderate to good validity (0.504 – 0.897). The level of agreement between results of apical gauging with hand files and those of apical gauging with GP are shown in Table 2 as well. Good to excellent agreement was observed between both gauging methods (0.831 – 0.932). Table 3 shows frequencies and percentages of the identical and non-identical matches between hand file and GP apical gauging methods; there were 64 (92.75%) identical matches between hand file and GP measurements.

Table 3. Matching between predicted diameters (mm) of both apical gauging methods

		GP			
		0.25	***0.30***	***0.35***	***0.40***
Hand files	***0.25***	46 (66.7%)	3 (4.3%)	0	0
	0.30	0	17 (24.6%)	1 (1.4%)	0
	0.35	0	0	1 (1.4%)	0
	0.40	0	0	1 (1.4%)	0

Discussion

The study aimed to determine the reliability and accuracy of the manual gauging technique with Ni-Ti K-files and the use of matching GP cones for determining the apical canal size after shaping, with SEM micrographs as the gold standard. The study was conducted on round canals and aimed to fill the gap in available literature on the topic.

Due to the anatomic variability of root canals, accurate measurement of the apical foramen is crucial for selecting the appropriate GP cone and ensuring successful obturation [13]. The study aimed to eliminate the influence of canal curvature and potential interferences along the canal walls in the middle or coronal thirds, which have been identified as possible reasons for unreliable cone fitting, by using straight canals in the evaluation [5]. Even when preflaring was performed, gauging with hand files was not precise [16]. By eliminating these factors, the study aimed to provide a more accurate assessment of the accuracy of manual gauging with Ni-Ti K-files and gauging with GP cones that match the instrument used for shaping. The use of matching GP cones with NiTi rotary files is becoming more popular in endodontics, as it is believed to provide a 3D obturation in less time and ensure a high volume of GP in the canal. However, discrepancies between Ni-Ti files and their corresponding GP cones are possible and often lead to a problematic master cone fit[2]. This might be due to repetitive pecking motions at the foramen which may enlarge the apical preparation compared to the instrument size [17]. Moreover, intramanufacturer variability between the instrument's diameter and its corresponding GP cone can lead an inappropriate fitting of the GP cone [18, 19]. Therefore, the master cone's fitting must be carefully checked before obturation, by trying different sizes. This is important because GP is dimensionally stable and it is desirable to have a maximum amount of GP in the canal and a minimum amount of sealer [2].

The first results of the present study showed that the mean of the true foramina diameters measured on the SEM was significantly greater than the mean of diameters predicted from the apical gauging method with hand files (P < 0.001*). The low agreement of gauging with NiTi K-Files with SEM data may have been partially related to the machining tolerance of 0.02 mm in the manufacturing of files [13]. The present findings are in agreement with previous studies that concluded that the NiTi K-file are inadequate in determining the true diameter of the apical canal[20, 21]. Amato et al. gauged the apical diameter in 60 samples and recorded 10% of errors with the IG-files and 70% of errors in the K-NiTi group. The study states that using k-files for apical gauging may not be reliable due to their key features such as the presence of coil and the active tip [21].

The second outcome evaluated in this study was the ability of GP cones to accurately gauge the foramen. The results showed that diameters predicted from the apical gauging with GP were significantly lower than the true diameters measured on the SEM (P < 0.001*). Several studies have been conducted on the variability of hand files and GP cones [2, 22]. The cone diameter variation permitted by the standardization varies from 0.05 to 0.07 mm [5]. Gordon et al reported that the matched-taper GP cone technique was effective; thus, when the shaping is performed with a single file, the root canal is ready to be obturated with a matching GP cone [23]. However, since tug-back is a subjective determinant that cannot be quantitively measured, Jeon et al. attempted to quantify it by measuring the pulling force generated in order to evaluate the correlation between the GP-filled area and the tug back force [22]. In contrast, the present study compared the ability of GP cones to gauge the apical foramen. In their study, Haupt et al. concluded that a variability in diameter and taper dimensions between single-file instrumentation systems and their corresponding GP cones can be expected, even though most dimensions are within the specifications. Therefore, the cone fitness should be verified even with corresponding cones [5]. The observation of the apical foramen in endodontics can be assessed using different techniques. Scanning electron microscope is one of the tools used [24]. Other techniques include the stereomicroscope, the micro-computed tomography and the digital microscope [11]. Among the methods used to study its morphology, micro-CT provides a detailed, three-dimensional view and performs in vivo and ex vivo cuts, but its use is limited due to the equipment needed and the high cost [24]. The SEM provides high-precision images, it permits an accurate measurement and is an accessible technique to observe a large sample. It also reduces the uncontrollable variables [11]. Thus, the SEM has been used in this study. Considering the present results, NiTi K-Files and gutta-percha cones are not accurate in gauging the apical foramen. However, the difference found between both gauging methods was not statistically significant. NiTi K-Files and gutta-percha cones have similar accuracy in gauging the apical foramen. To date, these two approaches in determining the apical canal size after shaping haven't been compared. Knowledge of root canal anatomy, and compaction techniques will help compensate for the gauging techniques' inaccuracy and will help obturate the root canal system.

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