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RESEARCH

Dimensional and cross-sectional compatibility of contemporary nickel–titanium files and their corresponding gutta-percha cones: A micro-computed tomography study

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Abstract

This study aimed to evaluate the dimensional and sectional compatibility between contemporary nickel–titanium (NiTi) root canal instruments and their corresponding gutta-percha (GP) cones with variable tapers, and to assess their compliance with ISO and ADA standards using micro-computed tomography (Micro-CT). Four NiTi file systems (ProTaper Next X2, HyFlex EDM OneFile, Reciproc Blue R25, and WaveOne Gold Primary) were analyzed. Their compatibility with corresponding GP cones was assessed based on diameter and taper measurements at 1 mm intervals (D1 to D16). Measurements were performed using Micro-CT imaging, and data were analyzed using descriptive statistics, independent t-tests, and one-way ANOVA with Bonferroni post hoc tests ($p < 0.05$). Compliance with International Organization for Standardization (ISO) and American Dental Association (ADA) standards was also assessed. The findings reveal significant dimensional discrepancies between files and GP cones, with GP cones generally exhibiting larger diameters. Reciprocating systems (WaveOne Gold and Reciproc Blue R25) demonstrated superior compatibility with GP cones compared to rotary systems (ProTaper Next and HyFlex EDM OneFile). GP cones adhered more closely to ISO and ADA standards than files. Significant mismatches were identified between NiTi instruments and their corresponding GP cones. Reciprocating systems showed better dimensional compatibility than rotary systems. These results highlight the need for careful evaluation of material pairing to ensure optimal clinical performance.

Keywords Nickel–titanium · Gutta-percha · Micro-CT · Dimensional compatibility

1 Introduction

The primary objective of endodontic therapy is either to prevent microbial contamination of the root canal system or to eliminate an existing infection. Achieving this objective requires thorough chemomechanical preparation of the canal system followed by an effective seal that prevents fluid infiltration (Chesler et al. 2013). Since the pioneering work of Walia et al. in 1988, which introduced nickel–titanium (NiTi) alloys into endodontics, significant progress has been made in the development of shaping instruments (Zhou et al. 2013). Nickel–titanium file systems have undergone numerous metallurgical and kinematic modifications aimed at improving flexibility and resistance to fracture (Chan et al. 2023). These developments have largely focused on increasing the durability of endodontic instruments and improving the efficiency of root canal shaping procedures. Today, a wide variety of rotary and reciprocating NiTi systems are available, providing enhanced cutting efficiency, flexibility, and resistance to cyclic fatigue (Chan et al. 2023; Gavini et al. 2018).

After canal preparation, obturation is frequently performed using gutta-percha (GP) cones that correspond to the instrumentation system, often through the single-cone technique (Marconi et al. 2022; Zavattini et al. 2020; Chybowski et al. 2018; Roizenblit et al. 2020; Holmes et al.

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2021). Many manufacturers therefore produce GP cones specifically designed to match the dimensions of their NiTi instrumentation systems. Previous studies have investigated the dimensional compatibility of proprietary GP cones with both single-file and multi-file NiTi rotary systems, particularly those characterized by constant tapers (Lask et al. 2006; Hatch et al. 2008; Cunningham et al. 2006). These studies have demonstrated that considerable variability may exist in both the diameter and taper of instruments and their corresponding GP cones among different brands. However, many contemporary NiTi systems exhibit variable tapers along the instrument length. Therefore, the present study evaluated the dimensional compatibility between commonly used NiTi systems with different kinematics (rotary and reciprocating) and their corresponding GP cones. The systems included in this investigation were ProTaper Next, HyFlex EDM, WaveOne Gold, and Reciproc Blue R25, which are widely used instrumentation systems designed to be used with dedicated GP cones in single-cone obturation techniques.

Standardization of endodontic instruments was first introduced by the International Organization for Standardization (ISO) in 1975 and has been updated periodically, most recently in 2019 (International Organization for Standardization 2019). The American National Standards Institute and the American Dental Association (ANSI/ADA) also established specifications for endodontic instruments and materials in 1976, which have subsequently been revised as instrumentation technologies evolved (Specification and no. 28 for endodontic files and reamers 1976). Currently, two principal standards regulate GP cones: ISO 6876 and ANSI/ADA Specification No. 78 (International Organization for Standardization 2021; American Dental Association 2006). Effective single-cone obturation depends on the dimensional compatibility between the gutta-percha cone and the shaping instrument. Proper dimensional matching ensures that the cone reaches the working length and adapts appropriately to the prepared canal. Dimensional discrepancies may result in overextension of the GP cone beyond the apical foramen or insufficient apical adaptation. Conversely, a cone that is oversized coronally may produce a false tug-back sensation and lead to an underfilled canal (Haupt et al. 2018).

The purpose of the present study was to evaluate the dimensional and cross-sectional compatibility between selected contemporary NiTi instrumentation systems and their corresponding GP cones using micro-computed tomography (micro-CT), while also assessing their compliance with ISO 3630—1:2019 and ANSI/ADA Specification No. 101 tolerance standards. Micro-CT was selected as the analytical method because it allows highly precise measurements, enables detailed examination of cross-sectional structures of both files and GP cones, and facilitates accurate superimposition of their images. In addition, as a non-contact imaging technique, micro-CT minimizes physical manipulation of the specimens during analysis, thereby reducing the risk of dimensional distortion (Angerame et al. 2020).

The null hypothesis tested in this study was that no significant dimensional differences would exist between nickel–titanium instruments and their corresponding gutta-percha cones.

2 Materials & methods

2.1 Sample selection

This study was conducted at the Department of Endodontics, Istanbul University, Istanbul, Turkey. In this study, size 25 instruments (0.25 mm tip diameter) with variable tapers were evaluated. Two different full rotating Ni–Ti systems HyFlex EDM One file (0.25 mm tip diameter and 08 taper first 4 mm from the tip than variable ~ taper until coronal portion to 04 taper) (Pedullà et al. 2016) (Coltène/Whaledent, Switzerland) and ProTaper Next X2 (0.25 mm tip diameter and 06 taper at first 3 mm from the tip than variable taper until the coronal part) (Dentsply, Maillefer, Ballaigues, Switzerland) and two reciprocating Ni–Ti systems Reciproc Blue R 25 (0.25 mm tip diameter and 08 taper for first 3 mm from the tip than variable taper until the coronal end) (VDW, Münih, Germany) and WaveOne Gold Primary 25.07 (0.25 mm tip diameter and 07 taper for first 3 mm from the tip than variable taper until the coronal part) (WOG; Dentsply Sirona, Ballaigues, Switzerland) were examined along with their corresponding GP cones for compliance with ADA and ISO specifications and their compatibility with each other using the Skyscan 1172 v.1.1.17 (Bruker Micro-CT, Kontich, Belgium) Micro-CT device. The gutta-percha cones used in the present study were the corresponding cones recommended by the same manufacturers for each instrument system. A prior power analysis was conducted using G*Power 3.1, based on the effect size (d = 2.16) reported by Chesler et al. With an alpha level of 0.05 and a statistical power of 0.80, the minimum required sample size was determined to be 6 specimens per group. However, according to ISO 3630—1 guidelines, at least 10 specimens are recommended for dimensional testing (International Organization for Standardization 2019; International Organization for Standardization 2021). Therefore, 12 samples per group were analyzed to ensure compliance with both statistical and standardization requirements. For each file system and its corresponding GP cones, samples were obtained from six different manufacturing lot numbers. Two specimens were selected from each lot, yielding 12 specimens per group. This approach aims to assess inter-lot consistency and minimize potential bias due to low-specific variation.

2.2 Micro-CT scanning procedure and measurement protocol

The diameters of the samples were measured according to the guidelines specified in ISO 3630 and ISO 6877 (International Organization for Standardization 2019; International Organization for Standardization 2021). The samples were stored at a temperature of (23 ± 2) °C for at least one hour before measurement. The samples were positioned vertically on the sample holder of the micro-CT device, with their tips pointing upward. Each scan took approximately two hours. The scanning was performed with a rotation angle of 0.400 degrees, an exposure time of 1500 ms, and an Al-Cu filter of 0.5 mm, using a voltage of 85 kV and a current of 115 µA, with two-frame averaging and a random movement of 20 degrees over 360 degrees. The resulting images had a voxel size of 9.99 µm. The TIFF images obtained were reconstructed using the NRecon v.1.6.10.6 (Bruker Micro-CT) software with 60% beam hardening correction, two smoothing steps, attenuation coefficient values ranging from 0 to 0.6, with ring artifact correction applied at level seven. Approximately 1300 two-dimensional (2D) axial cross-sectional images were obtained for each sample after reconstruction. The images of the endodontic files and GP cones were first corrected for tilt using the 3D registration function of Data Viewer v.1.5.1 (Bruker Micro-CT), and then the corresponding files and GP cones from the same brand were superimposed (Fig. 1).

The images were then transferred to CTAn v.1.17.7.2 (Bruker Micro-CT) for diameter measurements according to ADA standards (Fig. 2). In our study, the diameter measurements of the cross-sections at each D point for each GP cone and canal file were calculated by the CTAn v.1.17.7.2 software as the diameter of the smallest circle that can encompass the horizontal sections (Fig. 3). Every superimposed horizontal section for each brand was inspected. The previously obtained 3D models were visualized and analyzed using the CTVol (v.2.2.3, Bruker Micro-CT) software (Fig. 4).

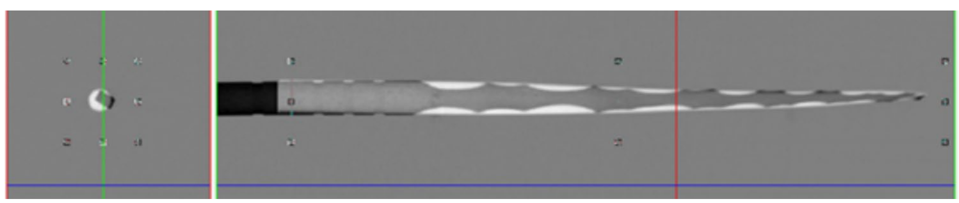

Fig. 1 Corresponding files and GP cones from the same brand were superimposed (ProTaper Next X2)

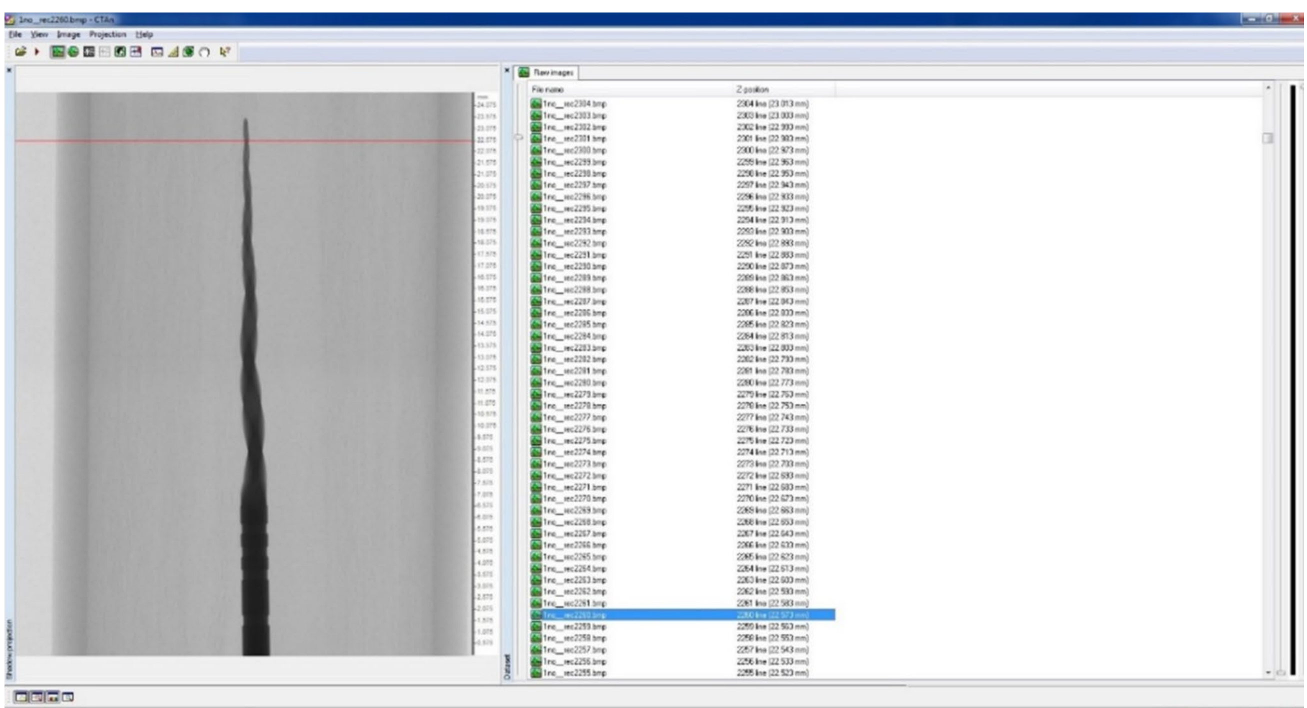

Fig. 2 CTAn v.1.17.7.2 (Bruker Micro-CT) program for diameter measurements

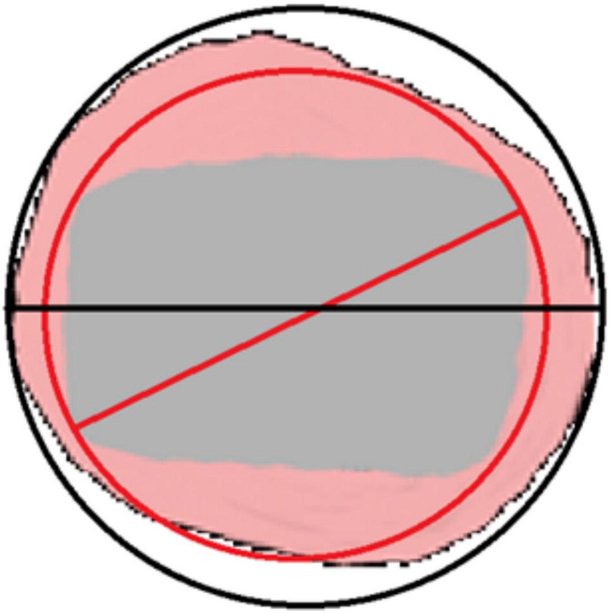

Fig. 3 ProTaper Next X2 GP and file horizontal sections representing D3 diameters. Red represents file and black represents GPs

Fig. 4 ProTaper Next X2 3D models

Given that the instrumentation systems used in this study had variable tapers, the diameters of the files and their corresponding GP cones were recorded at 1—mm increments from the tip (D1) to a distance of 16 mm (D16). After the diameters were measured, the taper values of the files and GP cones were calculated according to ADA standard no.78 and ISO specifications 3630—1 and 6876 (International Organization for Standardization 2019; International Organization for Standardization 2021; American Dental Association 2006). Taper measurements were calculated using the formula: Taper = (Diameter at D16—Diameter at D3)/(Distance between D16 and D3). Due to the variable taper, all the points were measured separately (Taper = Diameter difference between points/Distance between points) (Haupt et al. 2018). Since the measurement procedure required superimposition of the micro-CT images of the instruments and their corresponding gutta-percha cones, examiner blinding could not be implemented. All measurements were therefore performed according to standardized protocols to ensure reliable and reproducible results.

2.3 Statistical analysis

Descriptive statistics for continuous variables were reported as mean ± standard deviation. The assumption of normality was tested using both the Shapiro–Wilk and Kolmogorov–Smirnov tests. As the assumption of normality was satisfied, comparisons between two independent groups were performed using the independent samples t-test. For comparisons involving more than two groups, one-way analysis of variance (ANOVA) was applied, followed by Bonferroni correction for post hoc multiple comparisons. The significance level of $p < 0.05$ was considered statistically significant for all analyses.

3 Results

3.1 Compatibility

The diameter measurements of the root canal files and corresponding GP cones from D1 to D16 are shown in Tables 1 and 2. For the ProTaper Next system, mean diameter values of the files and GP cones were comparable at the D1 level. However, at the D3 and D16 levels, the GP cones had larger average diameter values compared to the files. In the WaveOne group, mean diameter values of the files were larger than those of the GP cones from D1 to D10, but after D10, the GP cones had larger diameters. In the Reciproc Blue R25 system, the files were larger than the GP cones up to the D13 level. In the HyFlex system, the GP cones were larger than the files at all levels.

The taper values of the root canal files and their corresponding GP cones are shown in Table 3. For the ProTaper system, the taper values of the GP cones were significantly larger than those of the files between D1-D3 and D3-D16. The WaveOne Gold GP cones and files had similar taper values between D1-D3, but the taper values of the GP cones were significantly larger than those of the files between D3-D16. In the Reciproc system, the taper values of the files and GP cones were the same. In the HyFlex system, the taper values of the GP cones were significantly larger than those of the files between D1-D3. The taper values between D3-D16 were similar for both GP cones and files.

3.2 Accuracy

The tolerance for the diameters of root canal files up to size 60 is ± 20 µm (International Organization for Standardization 2019). According to current standards, the acceptable diameter tolerance for GP cones can vary between 50 µm

Table 1 Diameter measurements of Protaper Next and HyFlex. Red indicates significant differences ($P < 0.05$)

Diameters	ProTaper Next File	GP	Comparison	p value	HyFlex File	GP	Comparison	p value
d1	0.2821 ± 0.0135	0.2890 ± 0.0187	G > F	0.315	0.2837 ± 0.0141	0.3071 ± 0.0166	G > F	0.001
d2	0.3296 ± 0.0129	0.3635 ± 0.0144	G > F	< 0.001	0.3722 ± 0.0133	0.3852 ± 0.0137	G > F	0.027
d3	0.3875 ± 0.0157	0.4156 ± 0.0167	G > F	< 0.001	0.4673 ± 0.0105	0.4775 ± 0.0142	G > F	0.058
d4	0.4398 ± 0.0150	0.4630 ± 0.0104	G > F	< 0.001	0.5212 ± 0.0086	0.5378 ± 0.0136	G > F	0.002
d5	0.5060 ± 0.0170	0.5186 ± 0.0114	G > F	0.044	0.5928 ± 0.0193	0.5985 ± 0.0135	G > F	0.413
d6	0.5658 ± 0.0166	0.5737 ± 0.0109	G > F	0.187	0.6412 ± 0.0122	0.6532 ± 0.0140	G > F	0.035
d7	0.6248 ± 0.0148	0.6349 ± 0.0144	G > F	0.105	0.6923 ± 0.0118	0.7116 ± 0.0154	G > F	0.002
d8	0.6823 ± 0.0145	0.6956 ± 0.0161	G > F	0.045	0.7402 ± 0.0173	0.7534 ± 0.0158	G > F	0.064
d9	0.7335 ± 0.0154	0.7553 ± 0.0130	G > F	0.001	0.7833 ± 0.0203	0.8005 ± 0.0157	G > F	< 0.001
d10	0.7954 ± 0.0147	0.8204 ± 0.0138	G > F	< 0.001	0.8186 ± 0.0149	0.8478 ± 0.0151	G > F	< 0.001
d11	0.8603 ± 0.0159	0.8910 ± 0.0095	G > F	< 0.001	0.8559 ± 0.0134	0.8960 ± 0.0145	G > F	< 0.001
d12	0.9169 ± 0.0154	0.9535 ± 0.0101	G > F	< 0.001	0.8771 ± 0.0097	0.9303 ± 0.0146	G > F	< 0.001
d13	0.9626 ± 0.0163	1.0245 ± 0.0313	G > F	< 0.001	0.9166 ± 0.0099	0.9707 ± 0.0159	G > F	< 0.001
d14	1.0013 ± 0.0338	1.0677 ± 0.0260	G > F	< 0.001	0.9372 ± 0.0100	1.0061 ± 0.0213	G > F	< 0.001
d15	1.0163 ± 0.0244	1.0997 ± 0.0227	G > F	< 0.001	0.9784 ± 0.0116	1.0489 ± 0.0167	G > F	< 0.001
d16	1.0559 ± 0.0233	1.1504 ± 0.0654	G > F	< 0.001	0.9925 ± 0.2794	1.0914 ± 0.0145	G > F	0.234

Table 2 Diameter measurements of Reciproc Blue R 25 and WOG. Red indicates significant differences ($P < 0.05$)

Diameters	Reciproc File	Reciproc GP	Comparison	p value	WOG File	WOG GP	Comparison	p value
d1	0.3212 ± 0.0097	0.3095 ± 0.0117	F > G	0.013	0.2981 ± 0.0137	0.2754 ± 0.0269	F > G	0.016
d2	0.4054 ± 0.0129	0.3945 ± 0.0120	F > G	0.044	0.3567 ± 0.0138	0.3577 ± 0.0120	F > G	0.858
d3	0.4915 ± 0.0116	0.4802 ± 0.0120	F > G	0.028	0.4297 ± 0.0165	0.4135 ± 0.0158	F > G	0.022
d4	0.5400 ± 0.0342	0.5305 ± 0.0114	F > G	0.373	0.4752 ± 0.0241	0.4661 ± 0.0112	F > G	0.248
d5	0.6005 ± 0.0112	0.5918 ± 0.0109	F > G	0.066	0.5411 ± 0.0120	0.5320 ± 0.0118	F > G	0.075
d6	0.6529 ± 0.0136	0.6398 ± 0.0089	F > G	0.011	0.6056 ± 0.0128	0.5973 ± 0.0146	F > G	0.151
d7	0.7043 ± 0.0144	0.7038 ± 0.0108	F > G	0.93	0.6677 ± 0.0155	0.6526 ± 0.0099	F > G	0.009
d8	0.7550 ± 0.0152	0.7419 ± 0.0094	F > G	0.019	0.7252 ± 0.0139	0.7062 ± 0.0106	F > G	0.001
d9	0.8002 ± 0.0120	0.7817 ± 0.0086	F > G	< 0.001	0.7821 ± 0.0108	0.7724 ± 0.0143	F > G	0.075
d10	0.8457 ± 0.0123	0.8192 ± 0.0080	F > G	< 0.001	0.8391 ± 0.0092	0.8355 ± 0.0099	F > G	0.365
d11	0.8949 ± 0.0109	0.8593 ± 0.0107	F > G	< 0.001	0.8959 ± 0.0086	0.9010 ± 0.0086	G > F	0.172
d12	0.9233 ± 0.0100	0.8988 ± 0.0107	F > G	< 0.001	0.9434 ± 0.0067	0.9577 ± 0.0137	G > F	0.004
d13	0.9456 ± 0.0083	0.9283 ± 0.0098	F > G	< 0.001	0.9727 ± 0.0063	0.9839 ± 0.0152	G > F	0.028
d14	0.9657 ± 0.0084	0.9592 ± 0.0094	F > G	0.088	0.9999 ± 0.0122	1.0094 ± 0.0170	G > F	0.13
d15	0.9794 ± 0.0208	0.9882 ± 0.0057	G > F	0.175	1.0528 ± 0.0238	1.0666 ± 0.0171	G > F	0.118
d16	1.0443 ± 0.0332	1.0264 ± 0.0244	G > F	0.148	1.1053 ± 0.0357	1.1238 ± 0.0302	G > F	0.183

Table 3 Taper values of the root canal files and their corresponding GP cones

	D1-D3 TAPER		Nominal Value D3-D16		D3-D16 TAPER		Nominal Value D3-D16	
Brand	GP	F	GP	F	GP	F	GP	F
ProTaper Next	0.063 ± 0.0025	0.052 ± 0.0047	0.06	0.06	0.056 ± 0051	0.051 ± 0.0012	~	~
HyFlex	0.085 ± 0.0038	0.092 ± 0.0050	0.08	0.08	0.047 ± 0.0012	0.04 ± 0.0015	~	~
WOG	0.069 ± 0.0082	0.066 ± 0.0043	0.07	0.07	0.054 ± 0.0026	0.051 ± 0.0032	~	~
Reciproc	0.085 ± 0.0031	0.085 ± 0.0042	0.08	0.08	0.042 ± 0.0021	0.042 ± 0.0023	~	~

Red indicates significant differences ($P < 0.05$)

GP gutta-percha, *F* File

and 70 µm, depending on the cone size (American Dental Association 2006). For GP cones up to size 25, a tolerance of 50 µm can be accepted. This variability means that a cone specified at a certain size could actually have a diameter of one size larger or smaller. For example, an ISO #25 cone could have the diameter of an ISO #30 or ISO #20 cone.

Figure 5 and Fig. 6 illustrate the accuracy of the nickel-titanium file diameters and the corresponding gutta-percha cone diameters, respectively, measured at various reference points.

The files and GP cones examined in this study had variable tapers. However, the taper between D1 and D3 was

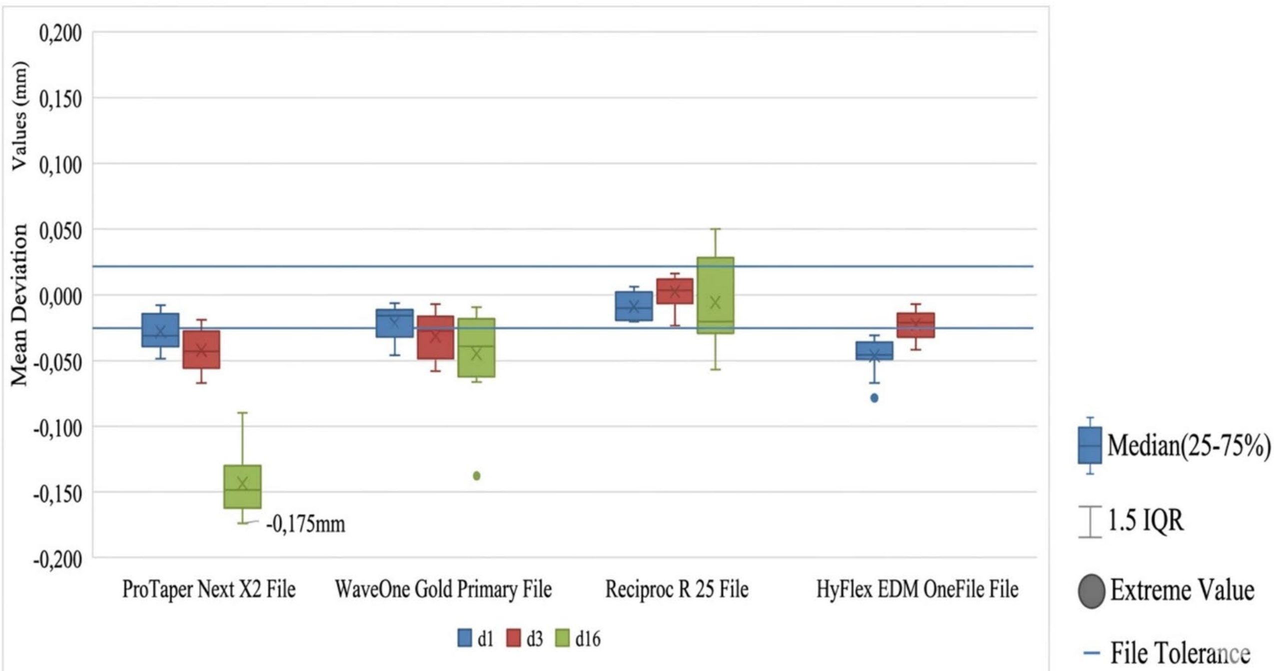

Fig. 5 Accuracy of the 4 file systems. The box plot illustrates the variability in diameter measurements against their nominal values

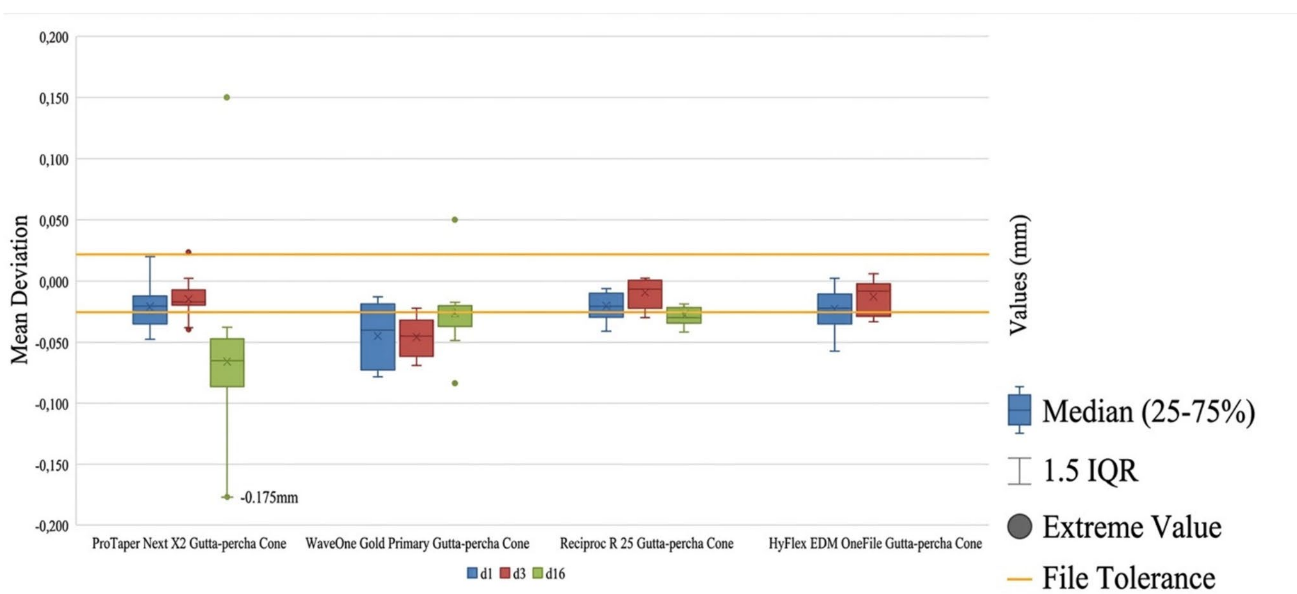

Fig. 6 Accuracy of 4 gutta-percha cones. The box plot illustrates the variability in diameter measurements against their nominal values

consistent for each brand. Therefore, the taper data between D1-D3 and D3-D16 were evaluated separately. According to the ANSI/ADA specification No. 101, the taper tolerance for all file and GP sizes is ± 0.05 mm (Root Canal Instruments: General Requirements 2010).

In the ProTaper Next X2 system, only 50% of the file diameters at the D1 level were within the standard tolerance range (20 µm). The nominal value for this level is 310 µm, but the average diameter was found to be 282.1 ± 13.5 µm. At the D3 level, only 16.6% of the files met the standards. At the D16 level, none of the files were compliant, with an average diameter of 1055.9 ± 23.3 µm (nominal value = 1200 µm). In contrast, all the GP cones in this group were within the 50 µm tolerance range at the D1 and D3 levels. However, at the D16 level, the average diameter was smaller than the nominal value, with a compliance rate of 33.3% (1150.4 ± 65.4 µm; nominal value = 1200 µm). Overall, the average diameters of the ProTaper Next files and GP cones were smaller than their nominal values.

In the WaveOne group, 75% of the file diameters at the D1 level (average diameter 298.1 ± 13.7 µm; nominal value = 320 µm) were within the standard tolerance range. However, at the D3 level, only 33% of the files were compliant, and at the D16 level, compliance decreased to 25%. For the GP cones in the same group, compliance was 58.8% at the D1 and D3 levels, but it increased to 91.6% at the D16 level (1123.8 ± 30.2 µm; nominal value = 1150 µm). All files and GP cones in this group were found to be smaller than their nominal values.

In the Reciproc Blue R25 group, all file diameters were compliant with the standards at the D1 (321.2 ± 9.7 µm; nominal value = 330 µm) and D3 (491.5 ± 11 µm; nominal value = 490 µm) levels. However, at the D16 level, compliance decreased to 33.3%. The average diameters of all the GP cones in this group were within the 50 µm tolerance range.

In the HyFlex EDM OneFile group, the diameters of the files at the D1 level were smaller than the nominal value, and none of them met the standards (283.7 ± 14.1 µm; nominal value = 330 µm). At the D3 level, 75% of the files were compliant. In contrast, the GP cones in this group were 91.6% compliant at the D1 level and 100% compliant at the D3 level. The nominal D16 diameter for the HyFlex EDM OneFile system is not specified in the manufacturer's technical documentation; therefore, a nominal comparison at the D16 level could not be performed.

When taper compliance with standards was evaluated, all files and GP cones in all groups were found to be within the standard range.

Cross-sectional evaluation revealed that all instruments retained their original design geometry (Fig. 7). Reciproc Blue R25 exhibited an S-shaped cross-section; ProTaper Next X2 had a rectangular cross-section; HyFlex EDM OneFile showed a quadratic cross-section at the tip, a trapezoidal form in the middle, and an almost triangular shape coronally; and WaveOne Gold Primary demonstrated a parallelogram-shaped cross-section (Fig. 7).

4 Discussion

Single-cone obturation has become a commonly applied technique in contemporary endodontic treatment, particularly after canal preparation with nickel-titanium instrumentation systems. However, even when the dimensions of these files and GP cones are within standard tolerance ranges, they

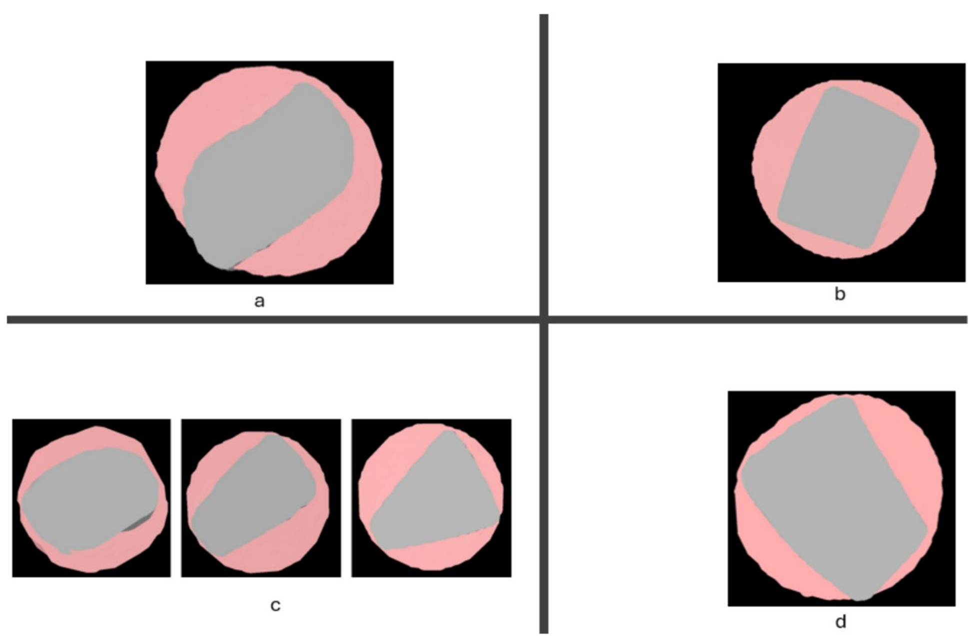

Fig. 7 Cross sectional evaluations of the systems. (a = Reciproc Blue R 25, b = ProTaper Next X2, c = HyFlex EDM OneFile and d = WaveOne Gold Primary)

may still exhibit dimensional discrepancies with each other (Chesler et al. 2013). When GP cones are larger than the root canal files, they may not reach the working length (Lask et al. 2006). Conversely, when GP cones are smaller than the files, they may extrude beyond the root apex, causing overfilling (Lask et al. 2006). GP cones with a taper greater than required may become stuck in the middle or coronal part of the root canal, creating a false sense of tug-back, which could lead to underfilling (Jeon et al. 2017). The tactile sensation of tug-back is considered an important clinical indicator of apical fit during obturation. A well-fitting gutta-percha cone that exhibits a distinct tug-back sensation is often considered an indicator of adequate apical adaptation and may contribute to improved sealing ability and reduced microleakage. The tug-back scoring system has been proposed as a method to evaluate the adaptation of gutta-percha cones within the root canal system (Jamleh et al. 2016). Alrahabi et al. (2016) investigated the clinical relevance of tug-back using CBCT and found that moderate tug-back was associated with better apical adaptation compared to cones that exhibited either minimal or excessive resistance (Alrahabi et al. 2016).

The literature contains numerous studies examining the compatibility of proprietary GP cones with single and multi-file Ni–Ti rotary systems, especially with constant taper (Lask et al. 2006; Hatch et al. 2008; Cunningham et al. 2006). However, most modern NiTi systems exhibit variable tapers along the length of the file and GP cone. Therefore, this study evaluated the compatibility of common Ni–Ti systems used under different kinematics with their corresponding GP cones. The selected files and GP cones had variable tapers, and the most commonly used tip size #25 was chosen (Haupt et al. 2018; Bajaj et al. 2017; Eskibağlar 2023).

In similar studies examining the compatibility of files and GP cones, various methods have been used for diameter measurement, including optical microscopy (Haupt et al. 2018; Martínez et al. 2023; Siqueira et al. 2001), scanning electron microscopy (Chesler et al. 2013), atomic force microscopy (Valois et al. 2004), digital calipers (Bajaj et al. 2017; Salles et al. 2013; Moule et al. 2002), and laser scanning (Mirmohammadi et al. 2018). Micro-CT has been widely used for studying root canal anatomy (Alak et al. 2023; Marceliano-Alves et al. 2023; Marceliano-Alves et al. 2016), canal filling (Türker et al. 2021; Xu et al. 2018), and shaping (Kaloustian et al. 2019a; Kaloustian et al. 2019b; Yalniz et al. 2021) due to its ability to provide three-dimensional images that closely resemble reality and allow for superimposition of before and after images (Kim et al. 2015; Fernandes et al. 2016). In this study, Micro-CT was used to achieve the most accurate measurements and to superimpose the images of the files and GP cones. Additionally, the minimum possible contact was made with the materials during measurements to avoid any changes in the specimens. Micro-CT enables non-destructive analysis and accurate comparison of specimens (Angerame et al. 2020; Alak et al. 2023; Marceliano-Alves et al. 2023; Marceliano-Alves et al. 2016; Türker et al. 2021; Xu et al. 2018; Kaloustian et al. 2019a; Kaloustian et al. 2019b; Yalniz et al. 2021; Kim et al. 2015; Fernandes et al. 2016). Samples were stored at (23 ± 2) °C for at least one hour prior to measurement in accordance with ISO specifications, which define standardized environmental conditions to ensure consistent and comparable dimensional assessments of dental materials.

In most similar studies, the diameter measurements of files and GP cones have been performed only at D1, D3, and D16 levels (Chesler et al. 2013; Eskibağlar 2023; Moule et al. 2002; Gergi et al. 2012; Kim et al. 2014). In some studies, measurements were taken only at D1, D3, and D11 levels (Bajaj et al. 2017). Martinez et al. (Martínez et al. 2023) emphasized the importance of the coronal reference point D16, stating that a difference in coronal diameters between the files and GP cones could prevent the GP cones from reaching the apex. Accurately locating the D0 point was not feasible in our study, similar to the observations reported in previous studies (Chesler et al. 2013; International Organization for Standardization 2021).

This limitation arose from the file samples rounded, non-cutting tip design. In our study, since we used Ni–Ti systems with variable tapers, measurements were taken at every millimeter from D1 to D16 to detect any potential dimensional variations more precisely.

This study revealed varying degrees of incompatibility between the root canal files and their corresponding GP cones across all systems. While the ProTaper Next X2 group showed significant incompatibility at all levels, all GP cones in this group were fully compliant with the standard tolerance range at the D1-D3 levels but were found to be smaller than the nominal value at D16. Chesler et al., in agreement with our findings, reported that all files from three different Ni–Ti systems (EndoSequence, K3, ProTaper) were smaller than their nominal values (Chesler et al. 2013). Haupt et al., contrary to other studies, reported that the GP cones claimed to be compatible with the files were within the acceptable range but generally smaller than their nominal size (Haupt et al. 2018). They also reported that Reciproc files and GP cones were mostly within the tolerance range (Haupt et al. 2018). Consistent with these findings, in our study, the Reciproc Blue R25 GP cones were 100% compliant with the standards. However, the file diameters at the D16 level were compliant in only 33.3% of the cases.

In the WaveOne Gold group, 75% of the file diameters at the D1 level were compliant with the standards, but only 58.8% of the GP cones met the standards. At the D3 level, none of the files were compliant, and only 8.33% of the GP cones were within the standard range. At the D16 level, none of the files met the standards, but all GP cones did.

In the HyFlex EDM OneFile group, it is known that the first 4 mm of the apical part has a fixed 0.08 taper, while the remaining part gradually reduces to a 0.04 taper (Pedullà et al. 2016). Therefore, only the D1 and D3 levels were examined. The compliance rates of the GP cones at the D1 and D3 levels were 91.6% and 100%, respectively. The files did not meet the standards at the D1 level but were 75% compliant at the D3 level.

All files and GP cones evaluated in this study were found to be smaller than their nominal values. The difference between the GP cones and files in terms of compliance with the ISO and ADA standards in favor of the GP cones may be due to the wider tolerance allowed for GP cones (50 µm) compared to that for files (20 µm).

In most studies evaluating the compatibility of different Ni–Ti systems with their corresponding GP cones, it has been shown that GP cones and files are often incompatible in terms of diameter (Chesler et al. 2013; Haupt et al. 2018; Bajaj et al. 2017; Martínez et al. 2023; Salles et al. 2013; Mirmohammadi et al. 2018). Similarly, in our study, varying degrees of incompatibility were observed between root canal files and GP cones across all groups. When comparing ProTaper Next and HyFlex with their corresponding GP cones, the GP cones were found to have larger average diameter values than the files. This suggests a potential issue with apical fit due to taper lock in these systems. In the WaveOne Gold group, the files were larger than the GP cones between D1 and D10, but the GP cones had larger diameter values between D11 and D16. Bajaj et al. reported that both ProTaper Next and WaveOne root canal files were smaller compared to their corresponding GP cones (Alrahabi et al. 2016). In contrast to Bajaj et al., in our study, the files in the WaveOne Gold group were significantly larger than the GP cones at D1 and D3 ($p < 0.05$). This difference may be due to different measurement methods or variations in manufacturing standards. For the ProTaper Next system, similar to Bajaj et al., mean diameter values of the GP cones were larger than those of the files (Alrahabi et al. 2016).

In our study, the Reciproc Blue R 25 group files had larger diameters in the apical and middle parts compared to the GP cones ($p < 0.05$). Haupt et al. reported that for Reciproc, the files were larger than the GP cones at the D3 level, similar to our study, but there was no difference between the files and GP cones in the apical D1 and D2 levels. In the coronal region, consistent with our findings, they reported that the #25 and #50 GP cones were significantly larger than the files (Haupt et al. 2018).

In terms of compatibility between GP cones and root canal files, the WaveOne Gold group demonstrated the most favorable average values across all measured levels (D1–D16). The ranking of the remaining systems in terms of dimensional compatibility was: Reciproc Blue R25 > HyFlex EDM OneFile > ProTaper Next X2, with ProTaper Next showing the least satisfactory results. Specifically, in the apical 3 mm region, the WaveOne Gold and Reciproc Blue R25 groups showed taper compatibility, whereas the ProTaper Next and HyFlex EDM OneFile groups did not.

The dimensional discrepancies observed between NiTi files and their corresponding GP cones may negatively affect the presence or quality of *tug-back*, potentially compromising the apical seal and overall obturation quality. Notably, none of the evaluated systems demonstrated complete diameter compatibility along the entire measured length. Reciprocating systems outperformed rotary systems in terms of dimensional matching, particularly in the apical region. Across all systems, GP cones generally exhibited larger diameters than their corresponding files; however, the degree of mismatch varied depending on the manufacturer.

This variability can be partially attributed to the differing tolerance limits defined by ISO 3630—1:2019 and ANSI/ADA Specification no.101 for canal instruments and GP cones. While canal files are manufactured with stricter dimensional tolerances, GP cones are allowed broader variations, which may have influenced the findings of this study in favor of the cones. These results underscore the importance of clinicians recognizing that dimensional compatibility between shaping files and GP cones should not be assumed, even within the same brand. Given the direct clinical relevance of these findings, it is essential to consider strategies that mitigate the impact of such dimensional inconsistencies. Fit should be carefully verified both clinically and radiographically to avoid potential obturation errors. Additionally, the adoption of bioceramic-based sealers—which rely on hydraulic condensation rather than a perfect geometric fit—or the use of thermoplasticized gutta-percha techniques could further compensate for these discrepancies, ultimately ensuring a more predictable and robust apical seal.

Manufacturers, in turn, should consider adopting more strict tolerances and enhancing quality control to improve the consistency between file systems and their matched GP cones. It is also important to acknowledge that other factors—such as root canal anatomy, apical morphology, obturation technique, and sealer properties—play a crucial role in the overall success of root canal filling.

Root canal anatomy may significantly influence the effectiveness of obturation techniques. In flattened or oval canals, circular instrumentation systems may not completely prepare the original canal morphology, leaving untouched areas along the canal walls. Therefore, the relationship between instrumentation systems and obturation quality should not be interpreted solely based on dimensional compatibility between files and gutta-percha cones, but also in the context of canal morphology. In addition, the present study evaluated only dimensional compatibility and did not directly assess clinical outcomes such as microleakage, void formation, or adaptation of the obturation material. Further experimental and clinical studies are needed to explore how the dimensional findings of this study translate into clinical outcomes.

5 Conclusions

None of the evaluated file systems and their corresponding gutta-percha cones demonstrated complete dimensional compatibility. Among the evaluated groups, WaveOne Gold and Reciproc Blue R25 demonstrated the highest level of compatibility, particularly in the apical region, while ProTaper Next X2 exhibited the least. Reciprocating systems showed better overall dimensional alignment compared to rotary systems.

Abbreviations *Ni-Ti*: Nickel Titanium; *GP*: Gutta-percha; *Micro-CT*: Micro-computed tomography

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Declarations

Ethics approval and consent to participate Not applicable.

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References

Alak SG, Keleş A, Keskin C, Martins JNR, Versiani MA (2023) Age-related changes in the morphology of the root canal system of mandibular first molars: a micro-CT study. Clin Oral Investig 27(8):4667–4675

Alrahabi M, Zafar MS, Aldammigh M (2016) Assessment of the apical fit of different gutta-percha cones to corresponding rotary files using cone-beam computed tomography. Saudi Endod J 6(3):132–136

American Dental Association (1976) ANSI/ADA Specification No. 28 for Endodontic Files and Reamers. American Dental Association

American Dental Association (2006) ANSI/ADA Standard No. 78-Dental Obturating Cones. American Dental Association Standards Technical Specifications, and Technical Reports

American Dental Association (2010) ANSI/ADA Specification No. 101 for Root Canal Instruments: General Requirements. American Dental Association

Angerame D, De Biasi M, Pecci R, Bedini R (2020) Filling ability of three variants of the single-cone technique with bioceramic sealer: a micro-computed tomography study. J Mater Sci Mater Med 31(11):91

Bajaj N, Monga P, Mahajan P (2017) Assessment of consistency in the dimension of gutta-percha cones of ProTaper Next and WaveOne with their corresponding number files. Eur J Dent 11(02):201–205

Chan WS, Gulati K, Peters OA (2023) Advancing nitinol: from heat treatment to surface functionalization for nickel–titanium (NiTi) instruments in endodontics. Bioact Mater 22:91–111

Chesler MB, Tordik PA, Imamura GM, Goodell GG (2013) Intramanufacturer diameter and taper variability of rotary instruments and their corresponding gutta-percha cones. J Endod 39(4):538–541

Chybowski EA, Glickman GN, Patel Y, Fleury A, Solomon E, He J (2018) Clinical outcome of non-surgical root canal treatment using a single-cone technique with Endosequence bioceramic sealer: a retrospective analysis. J Endod 44(6):941–945

Council on Dental Materials and Devices (1976) New American Dental Association specification no. 28 for endodontic files and reamers. J Am Dent Assoc 93(4):813–7

Cunningham KP, Walker MP, Kulild JC, Lask JT (2006) Variability of the diameter and taper of size #30, 0.04 gutta-percha cones. J Endod 32(11):1081–1084

Eskibağlar M (2023) Evaluation of compatibility of file and gutta-percha cones in three different endodontic systems using scanning electron microscopy. Turk Endod J 8(1):1–7

Fernandes JS, Appoloni CR, Fernandes CP (2016) Accuracy evaluation of an X-ray microtomography system. Micron 85:34–38

Gavini G, Santos MD, Caldeira CL, Machado MEDL, Freire LG, Iglecias EF et al (2018) Nickel-titanium instruments in endodontics: a concise review of the state of the art. Braz Oral Res 32:44–65

Gergi R, Abou Rjeily J, Osta N, Sader J, Naaman A (2012) Taper preparation variability compared to current taper standards using computed tomography. Int J Dent 2012:1–4

Hatch GW, Roberts S, Joyce AP, Runner R, McPherson JC (2008) Comparative study of the variability of 0.06 tapered rotary endodontic files to current taper standards. J Endod 34(4):463–465

Haupt F, Seidel M, Rizk M, Sydow HG, Wiegand A, Rödig T (2018) Diameter and taper variability of single-file instrumentation systems and their corresponding gutta-percha cones. J Endod 44(9):1436–1441

Holmes S, Gibson R, Butler J, Pacheco R, Askar M, Paurazas S (2021) Volumetric evaluation of 5 root canal obturation methods in TrueTooth 3-dimensional–printed tooth replicas using nano–computed tomography. J Endod 47(3):485-491.e4

International Organization for Standardization (2019) ISO 3630-1:2019. Dentistry — Root canal instruments — Part 1: General requirements and test methods. International Organization for Standardization

International Organization for Standardization (2021) ISO 6877:2021. Dentistry — Endodontic obturating points. International Organization for Standardization

Jamleh A, Awawdeh L, Albanyan H, Masuadi E, Alfouzan K (2016) Apical gutta-percha cone adaptation and degree of tug-back sensation after canal preparation. Saudi Endod J 6(3):131–135
Jeon SJ, Moon YM, Seo MS (2017) Quantification of the tug-back by measuring the pulling force and micro-computed tomographic evaluation. Restor Dent Endod 42(4):273
Kaloustian MK, Nehme W, El Hachem C, Zogheib C, Ghosn N, Michetti J et al (2019) Evaluation of two shaping systems and two ultrasonic irrigation devices in removing root canal filling material from mesial roots of mandibular molars: a Micro-CT study. Dent J (Basel) 7(1):2
Kaloustian MK, Nehme W, El Hachem C, Zogheib C, Ghosn N, Mallet JP et al (2019) Evaluation of two shaping systems and two sonic irrigation devices in removing root canal filling material from distal roots of mandibular molars assessed by micro–CT. Int Endod J 52(11):1635–1644
Kim KW, Cho KM, Park SH, Choi KY, Karabucak B, Kim JW (2014) A comparison of dimensional standard of several nickel-titanium rotary files. Restor Dent Endod 39(1):7
Kim Y, Perinpanayagam H, Lee JK, Yoo YJ, Oh S, Gu Y et al (2015) Comparison of mandibular first molar mesial root canal morphology using micro-computed tomography and clearing technique. Acta Odontol Scand 73(6):427–432
Lask J, Walker M, Kulild J, Cunnigham K, Shull P (2006) Variability of the diameter and taper of size #30, 0.04 nickel-titanium rotary files. J Endod 32(12):1171–1173
Marceliano-Alves M, Alves FRF, Mendes D, Provenzano JC (2016) Micro–computed tomography analysis of the root canal morphology of palatal roots of maxillary first molars. J Endod 42(2):280–283
Marceliano-Alves MF, de Coutinho TM, Ronquete V, Goulard PA, do Nascimento LM, de Almeida dos Santos A et al (2023) Internal morphology of distal roots of mandibular first molars revealed by computed microtomography. Aust Endod J 49(S1):1–8
Marconi DF, da Silva GS, Weissheimer T, Silva IA, Só GB, Jahnke LT et al (2022) Influence of the root canal filling technique on the success rate of primary endodontic treatments: a systematic review. Restor Dent Endod 47(4):e40
Martínez I, Lozano A, Sanz J, Forner L, Llena C (2023) Diameter and taper variability of gutta-percha cones adapted to TruNatomyTM and RotateTM rotary file systems. J Clin Exp Dent 15:e17–e22
Mirmohammadi H, Sitarz M, Shemesh H (2018) Intra-manufacture diameter variability of rotary files and their corresponding gutta-percha cones using laser scan micrometre. Iran Endod J 13(2):159–162
Moule AJ, Kellaway R, Glarkson R, Rowell J, Macfarlane R, Lewis D et al (2002) Variability of master gutta-percha cones. Aust Endod J 28(1):38–43
Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM, La Rosa G, Rapisarda E (2016) Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. J Endod 42(1):156–159
Roizenblit RN, Soares FO, Lopes RT, dos Santos BC, Gusman H (2020) Root canal filling quality of mandibular molars with Endosequence BC and AH Plus sealers: a micro-CT study. Aust Endod J 46(1):82–87
Salles AA, Cord CB, Sonnemann TS, de Melo TAF, Irala LED, de Oliveira EPM (2013) Comparative analysis of the diameter of MTwo® system gutta-percha points in relation to their corresponding instruments. Rev Sul-Bras Odontol 10(4):328–333
Siqueira JF, Rôças IN, Valois CRA (2001) Apical sealing ability of five endodontic sealers. Aust Endod J 27(1):33–35
Türker SA, Uzunoğlu-Özyürek E, Kaşikçi S, Öndeş M, Geneci F, Çelik HH (2021) Filling quality of several obturation techniques in the presence of apically separated instruments: a Micro-CT study. Microsc Res Tech 84(6):1265–1271
Valois CRA, Silva LP, Azevedo RB, Costa ED (2004) Atomic force microscopy study of gutta-percha cone topography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 98(2):250–255
Xu H, Qiu XH, Zhang GD, Zhang FM (2018) [Evaluation of the filling quality of different root canal obturation techniques using micro-CT]. Shanghai Kou Qiang Yi Xue 27(4):349–353
Yalniz H, Koohnavard M, Oncu A, Celikten B, Orhan AI, Orhan K (2021) Comparative evaluation of dentin volume removal and centralization of the root canal after shaping with the ProTaper Universal, ProTaper Gold, and One-Curve instruments using micro-CT. J Dent Res Dent Clin Dent Prospects 15(1):47–52
Zavattini A, Knight A, Foschi F, Mannocci F (2020) Outcome of root canal treatments using a new calcium silicate root canal sealer: a non-randomized clinical trial. J Clin Med 9(3):782
Zhou H, Peng B, Zheng Y (2013) An overview of the mechanical properties of nickel–titanium endodontic instruments. Endod Topics 29(1):42–54