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Comparison of the dimensional compatibility between gutta-percha cones and files of three variable-taper endodontic systems

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Abstract

Aim: This study aimed to evaluate the dimensional fit between the finishing files of three commonly used endodontic file systems (ProTaper Ultimate, WaveOne Gold, and Reciproc) and the gutta-percha (GP) cones claimed by their manufacturers to be compatible with these files.

Methods: In this in vitro study, 20 finishing files and 20 corresponding GP cones from each of the ProTaper Ultimate, WaveOne Gold, and Reciproc systems were examined (a total of 60 files and 60 GP cones). Diameters were measured at 1, 4, 9, and 16 mm (D1, D4, D9, and D16, respectively) from the apical tip using a dental operating microscope and ImageJ software. Data were statistically analyzed using the Paired-samples t-test and one-way analysis of variance (ANOVA) ($p<0.05$).

Results: Statistically significant diameter discrepancies ($p<0.05$) were observed between the files and their corresponding GP cones across all systems. At D1, file diameters were consistently greater than those of the compatible GP cones, whereas in the Reciproc system at D16, the GP cones exhibited significantly larger diameters than the files.

Conclusion: This study revealed dimensional discrepancies between files and manufacturer-designated “compatible” GP cones, potentially compromising obturation quality. Clinicians should verify cone fit both radiographically and clinically through the “tug-back” sensation, rather than relying solely on manufacturer claims. When incompatibility is detected, tip adjustment using a GP gauge may be necessary.

Keywords: Gutta-percha, nickel-titanium, rotary file, root canal treatment, dimensional compatibility, taper, gauge, material testing

Introduction

Gutta-percha (GP) cones are used in dentistry for filling root canals. GP was introduced in dentistry by Edwin Truman in 1847 (1). Initially, it was used as a filling material and denture base material. In 1867, GP was popularized as a root canal filling material by Bowman (2). One of the primary aims of root canal therapy is to achieve three-dimensional obturation (3). To meet this goal, it is essential to achieve proper adaptation of the GP filling material to the canal walls (4). The diameter of the final instrument used for canal shaping and the use of the corresponding GP cone are critical for achieving an accurate three-dimensional apical seal (5). A well-sealed filling that is radiographically free of voids is associated with higher success rates (6). This requires that both the instrument and the corresponding GP cone are manufactured according to the same standard protocol (7). To achieve more conservative canal shaping, newly developed rotary instrument systems with reduced taper designs are being continually introduced to the market (8).

The diameter and taper tolerances of endodontic files and GP cones are governed by ISO 3630-1:2019 and ISO 6877, respectively (9). Without modification, these standards were subsequently adopted by the American National Standards Institute/American Dental Association (10). No new standards have been defined following the introduction of variable taper endodontic systems. Regarding instruments with non-standard tapers, ISO 3630-1:2019 specifies that “diameters and tolerances shall be at the discretion of the manufacturer” (9).

The tolerance for GP cones, which has remained unchanged since ISO 6877 was first published in 1995, specifies a diameter tolerance of 0.05 mm for sizes 10-25 and 0.07 mm for sizes 30–140 mm. This means that GP cones may be one to two sizes smaller or larger than the specified ISO size (11). One of the most common challenges in the use of GP, despite the existence of an international regulatory standard (ISO 3630-1:2019) (3), is the lack of standardization (12). Numerous studies have identified inconsistencies between endodontic instruments and GP cones, resulting from this lack of standardization. These discrepancies can lead to clinician frustration, prolonged treatment time, and adverse effects on clinical outcomes (1, 13, 14).

If a GP cone is undersized, it may fail to adequately fill the canal, leaving voids and increasing the risk of reinfection. Conversely, if the file is oversized, it may not reach the working length and may compromise the apical seal of the canal. Currently, several manufacturers claim to produce GP cones compatible with specific file systems. Dentsply Sirona (DS) and VDW are examples of such manufacturers. DS is a widely used variable-taper endodontic system, and its associated manufacturer markets GP cones corresponding to its specific file sizes. Unlike conventional GP cones made from natural rubber latex, these GP cones are manufactured to match their reference files in terms of dimensions (i.e., diameter and taper) (15, 16). To the best of our knowledge, few studies have examined the dimensional compatibility between these instruments and their corresponding GP cones, given the recent introduction of these systems.

The aim of the present study was to evaluate the diameter compatibility between master files and their manufacturer-designated corresponding GP cones in two Dentsply Sirona rotary systems and one VDW reciprocating system. In this context, the diameters at D1, D4, D9, and D16 were measured using a computer-assisted program and compared to determine whether the dimensional consistency claimed by the manufacturers was maintained. To the best of our knowledge, this is the first study to assess these three systems collectively in terms of diameter standardization.

Materials and Methods

This study was an experimental investigation performed in a laboratory environment to evaluate the diameter consistency of rotary files of mechanical endodontic preparation systems and their compatible GP main cones. This in vitro study involved only materials and therefore did not require ethical committee approval, as no human or animal subjects were used in the study.

Material Selection

In this study, ProTaper Ultimate (Dentsply, Ballaigues, Switzerland), WaveOne Gold (Dentsply, Ballaigues, Switzerland), and Reciproc (VDW, Munich, Germany) and their corresponding gutta-percha cones produced specifically for these systems were used. For each system, the files and cones corresponding to the finishing size were evaluated.

A total of six groups, one file (n=20) and one GP cone (n=20) group, were formed for each system, and a total of 120 samples (60 files and 60 GP cones) were examined. GP cone samples were randomly selected from different packaging and lot numbers to minimize possible variations arising from production, transportation, or storage conditions.

Measurement Protocol

All tests and conditions of the samples (temperature 23 ± 2 °C, 50% ± 5 relative humidity, 24 hours) were carried out in accordance with ISO 3630-1:2019 and ISO 6877:2006 standards.

File and GP cone images were obtained using a dental operating microscope (Zumax, Suzhou, China) and an integrated camera (Canon, Tokyo, Japan) set to 26.5 x magnification, in accordance with the ISO 3630-1:2019 standard (Fig. 1). After all samples were displayed under standardized conditions, the images were transferred to the computer environment.

Diameter measurements were performed at points D1, D4, D9, and D16 of the file and GP cones using the ImageJ software (University of Wisconsin, Madison, WI, US). These points represent distances from the apical end (D0) of the instrument at 1, 4, 9, and 16 mm, respectively (Fig. 2). A graphical illustration of this study is shown in Figure 3.

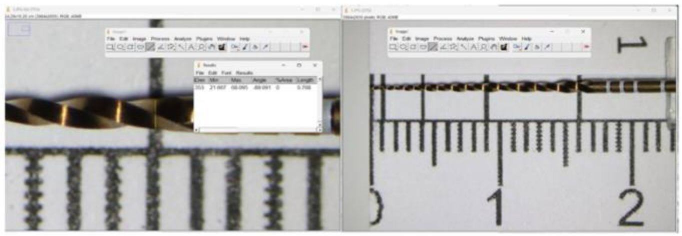

Figure 1. Photographic images of randomly selected files and their corresponding GP cones from different packages.

Figure 2. Diameter measurements were performed digitally using the ImageJ software.

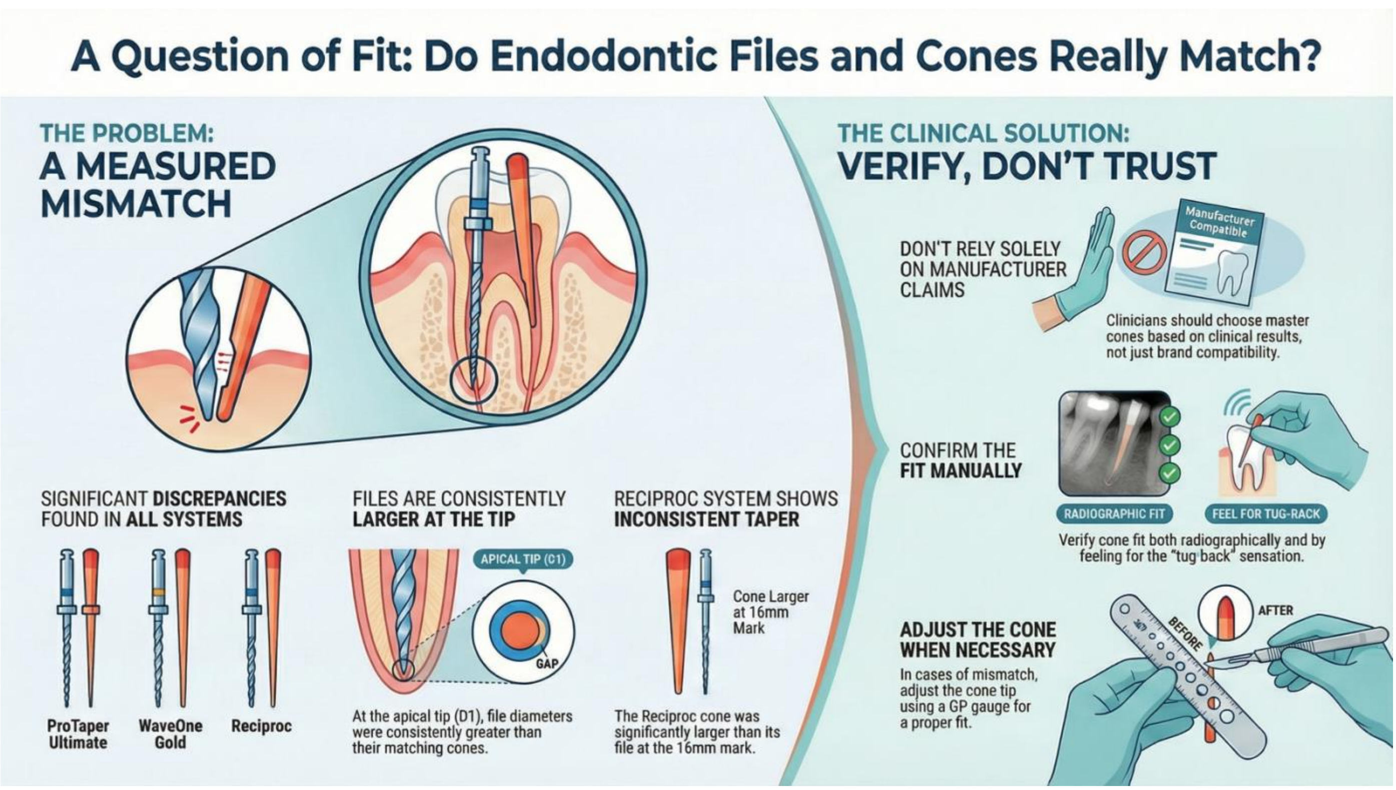

Figure 3. Graphical illustration of the study

Statistical Analysis

The data obtained in the study were analyzed using the Statistical Package for Social Sciences (SPSS) (V25.0; IBM Inc., Armonk, NY, USA). The conformity of the data to a normal distribution was evaluated using kurtosis and skewness values. For normally distributed data, Paired-Samples t-test was used to evaluate the differences between the file and GP diameter measurements of the same system. The Independent Samples t-test was applied to compare the differences between the measurements made by the two endodontists (consistency between specialists). Results were considered statistically significant at $p<0.05$.

Results

The study findings focused on comparing the diameters of the files and compatible GP cones at different points for each endodontic system and assessing the consistency between the two specialists' measurements. The statistical evaluation results for all measurements are presented in Table 1.

In the ProTaper Ultimate system, it was observed that the file diameter at point D1 ($\bar{X}$=0.311 mm) was statistically significantly higher than the GP diameter ($\bar{X}$=0.278 mm) in Endodontist 1's measurements ($p<0.001$). In the measurements of Endodontist 2, it was determined that the file diameters were significantly larger than the GP diameters at both D1 (file: $\bar{X}$=0.319 mm, GP: $\bar{X}$=0.283 mm; $p<0.001$) and D4 (file: $\bar{X}$=0.489 mm, GP: $\bar{X}$=0.467 mm; p=0.033).

In the data related to the Reciproc system, Endodontist 1 found the file diameter ($\bar{X}$=0.498 mm) to be significantly higher than the GP diameter ($\bar{X}$=0.461 mm) at D4 (p=0.045), while at point D16, conversely, the GP diameter ($\bar{X}$=1.065 mm) was statistically significantly higher than the file diameter ($\bar{X}$=0.908 mm) ($p<0.001$). Endodontist 2 also confirmed that the file diameter at D1 ($\bar{X}$=0.332 mm) was larger than that of GP ($\bar{X}$=0.312 mm) (p=0.047) and that the GP diameter ($\bar{X}$=1.070 mm) was significantly higher than the file diameter ($\bar{X}$=0.912 mm) at point D16 ($p<0.001$).

In the WaveOne Gold system, Endodontist 1 determined that the file diameter ($\bar{X}$=0.313 mm) was significantly higher than the GP diameter ($\bar{X}$=0.270 mm) only at D1 (p=0.001), while Endodontist 2 determined that D1 (file: $\bar{X}$=0.328 mm, GP: $\bar{X}$=0.272 mm; $p<0.001$), D4 (file: $\bar{X}$=0.481 mm, GP: $\bar{X}$=0.448 mm; p=0.046) and D9 (file: $\bar{X}$=0.748 mm, GP: $\bar{X}$=0.688 mm; p=0.041), the file diameters exceeded the GP diameters statistically significantly at three different points.

When the measurement consistency between experts was examined, it was noted that there were systematic differences in both file and GP measurements. The mean of Endodontist 2 ($\bar{X}$=0.326 mm) was statistically significantly higher than the mean of Endodontist 1 ($\bar{X}$=0.314 mm) in the file diameter measurements at point D1 ($p<0.001$). Similarly, in GP diameter measurements, D1 (Endodontist 2: $\bar{X}$=0.289 mm, Endodontist 1: $\bar{X}$=0.286 mm; p=0.001), D4 (Endodontist 2: $\bar{X}$=0.461 mm, Endodontist 1: $\bar{X}$=0.457 mm; $p<0.001$), D9 (Endodontist 2: $\bar{X}$=0.687 mm, Endodontist 1: $\bar{X}$=0.683 mm; p=0.004) and D16 (Endodontist 2: $\bar{X}$=0.974 mm, Endodontist 1: $\bar{X}$=0.971 mm; p=0.002), Endodontist's measurements recorded statistically significant, but practically higher, values with small differences compared to Endodontist 1's measurements (Figs. 4, and 5).

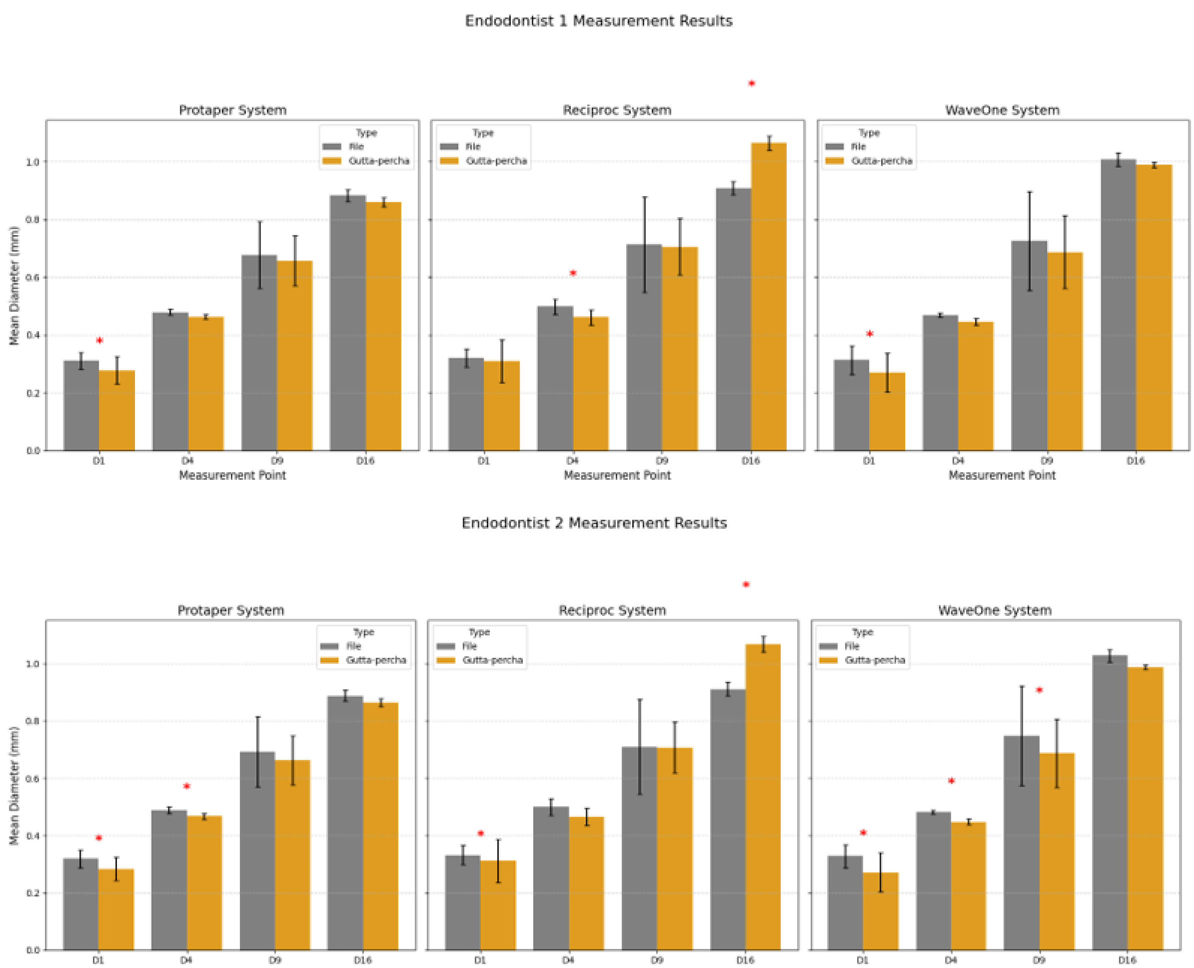

Figure 4. Column chart representation of the measurement results obtained by both operators. The gray columns represent the files, while the orange columns represent the gutta-percha.

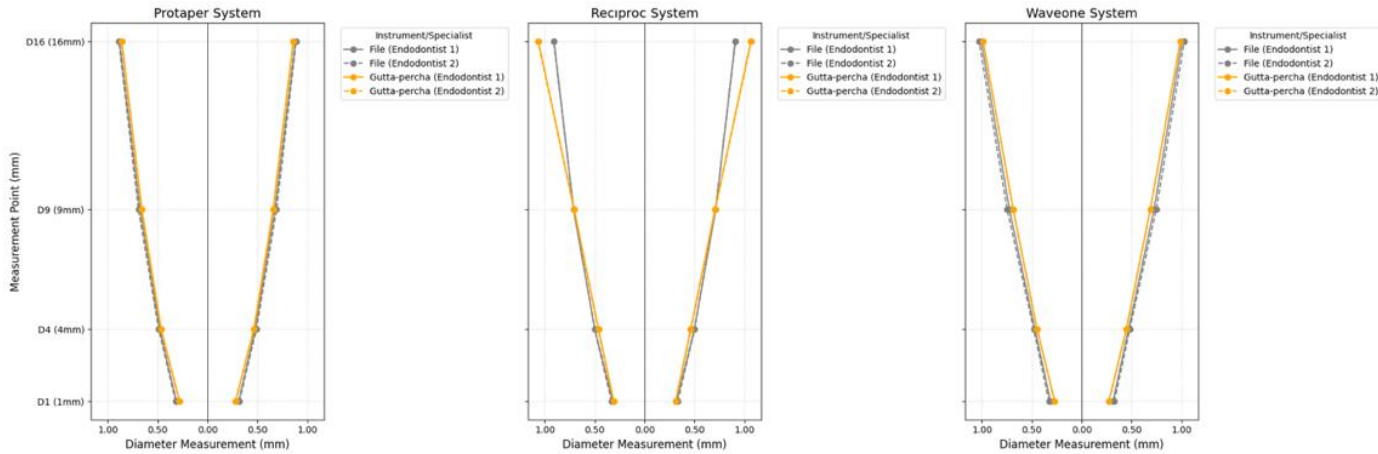

Figure 5. Graphical representation of the measurement results obtained by both operators. The gray lines represent the files, while the orange lines represent the gutta-percha cones.

Table 1. Evaluation of diameter measurement results at D1, D4, D9, and D16 points.

Expert	System	Measurement points	File or GP	$\bar{X}$	SD	t-test	p
Endodontist 1	Protaper	D1	File	0.311	0.029	4.702	**0.000***
			GP	0.278	0.010		
		D4	File	0.479	0.048	1.484	**0.153**
			GP	0.463	0.008		
		D9	File	0.677	0.087	1.001	**0.329**
			GP	0.657	0.016		
		D16	File	0.883	0.115	0.898	**0.380**
			GP	0.859	0.021		
	Reciproc	D1	File	0.320	0.032	1.204	**0.236**
			GP	0.309	0.026		
		D4	File	0.498	0.074	2.121	**0.045***
			GP	0.461	0.026		
		D9	File	0.713	0.099	0.326	**0.748**
			GP	0.706	0.024		
		D16	File	0.908	0.166	-4.170	**0.000**
			GP	1.065	0.023		
	WaveOne	D1	File	0.313	0.049	3.891	**0.001***
			GP	0.270	0.006		
		D4	File	0.469	0.066	1.524	**0.143**
			GP	0.446	0.012		
		D9	File	0.725	0.126	1.347	**0.194**
			GP	0.687	0.009		
		D16	File	1.007	0.171	0.482	**0.635**
			GP	0.989	0.023		
Endodontist 2	Protaper	D1	File	0.319	0.031	4.974	**0.000***
			GP	0.283	0.011		
		D4	File	0.489	0.041	2.281	**0.033***
			GP	0.467	0.010		
		D9	File	0.693	0.085	1.574	**0.131**
			GP	0.663	0.014		
		D16	File	0.889	0.123	0.905	**0.376**
			GP	0.864	0.019		

	Reciproc	D1	File	0.332	0.033	2.056	**0.047***
			GP	0.312	0.029		
		D4	File	0.500	0.075	1.893	**0.070**
			GP	0.466	0.031		
		D9	File	0.710	0.090	0.095	**0.925**
			GP	0.708	0.028		
		D16	File	0.912	0.166	-4.201	**0.000***
			GP	1.070	0.024		
	WaveOne	D1	File	0.328	0.040	6.063	**0.000***
			GP	0.272	0.007		
		D4	File	0.481	0.068	2.123	**0.046***
			GP	0.448	0.011		
		D9	File	0.748	0.120	2.189	**0.041***
			GP	0.688	0.009		
		D16	File	1.029	0.174	1.024	**0.318**
			GP	0.989	0.022		

*p<0.05, GP: Gutta-percha

Discussion

Root canal treamtent is both time-consuming and costly, and may cause frustration for clinicians, particularly when the tip diameters and tapers of NiTi rotary files do not match those of their corresponding GP cones. During root canal obturation, differences in file and cone dimensions can cause the GP cone to extend toward the periapical tissues, fail to fit properly against the canal walls, or become prematurely engaged due to frictional resistance (14). Discrepancies were observed between the sizes of NiTi rotary files and their corresponding GP cones in the systems evaluated in this study.

Optical microscopes (17), measuring microscopes (18), laser micrometers (14), and scanning electron microscopes (19) have been used. We also used the dental operation microscope in our study.

GP cones, being partially crystalline and viscoelastic polymeric materials, are susceptible to dimensional changes in response to environmental variations. The observed diameter variability of GP cones may result from the inherently high plasticity of GP (17). Mechanical deformation may still occur despite adherence to standardized production and packaging procedures. Similarly, during transportation and storage, it can cause shrinkage or expansion due to extreme temperatures. GP mastert cones are more convenient to store in the refrigerator; however, there is still not enough information about the effect of environmental changes such as temperature on the dimensional stability of GP cones (20). In this study, GP cones were stored at room temperature.

The D1 tip diameter of the GP to be used as the main cone should be as close as possible to the diameter of the tool in the respective location, since this is the piece of tool used to create the apical stop (21). This size compatibility between the GP cone diameter and the tool will ensure a proper fit of the master cone (22). In this study, measurements at multiple D points allowed for the assessment of diameter compatibility in the apical, mid, and coronal thirds of each system.

Based on current standards, which are followed by most reputable manufacturers, the acceptable diameter of GP cones ranges from 0.05 to 0.07 mm. Consequently, a cone labeled with a specific size may correspond to one size larger or smaller; for instance, an ISO #25 cone could effectively be ISO #20 or ISO #30. The differences observed between endodontic files and their corresponding GP cones in this study align with findings reported in previous literature. Chesler et al. examined the EndoSequence, K3, and ProTaper systems and reported significant differences among their internal diameters and tapers (23). Haupt et al. evaluated the F360 system and reported that the corresponding GP cones were significantly smaller than the matching files (7). Our findings revealed that, particularly at the D1 level, the file diameters exceeded those of the corresponding GP cones in all three brands tested. Salles et al. examined the harmony of dimensions between the Mtwo file system and GP and showed that the diameters of GP of 25/.07 magnitude were significantly higher than the corresponding instruments in D1 and D3, and that gutta-perchas of 25/.06, 25/.07, 30/.05 and 35/.04 in D11 had higher diameters (22). Bajaj et al. reported that the diameters of ProTaper Next and WaveOne GP cones were greater than those of their corresponding files (1). Keith et al. reported that, in the apical third region, the mean file diameters of ProTaper and EdgeEndo systems were significantly smaller than those of their corresponding GP cones (10). In these studies, contrary to our study, GP cone diameters were measured larger than the corresponding files.

Limitations

This study is limited by the human eye's restricted ability to resolve spatial and temporal details. Although the use of optical devices such as microscopes can mitigate these shortcomings, these instruments also face inherent constraints, including the diffraction limit. Therefore, optical measurement techniques are inherently prone to potential sources of error. In this study, the distance measurement between two points was determined between the outermost points of the file and GP cones within the limits of the human eye with the Imajej J program. Practitioner error is one of the limiting aspects of the study.

Conclusion

The master cone should be chosen by clinicians according to the clinical results of instrumentation, rather than the size suggested by the manufacturer. Radiographically, the fit of the master GP cone and its apical adaptation should be verified. In cases of mismatch, clinicians may select a smaller cone or adjust the tip using a GP gauge to achieve a proper fit.

Disclosures

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Author Contributions: Concept – N.B., B.B.; Design – N.B., B.B.; Supervision – N.B.; Materials – N.B.; Data collection &/or processing – N.B., B.B.; Analysis and/or interpretation – N.B., B.B.; Literature search – N.B., B.B.; Writing – N.B., B.B.; Critical review – N.B., B.B.

Conflict of Interest: The authors declare that there is no conflict of interest.

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