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Evaluation of Gutta-Percha-Filled Areas in Curved and Straight Root Canals Using Three Reciprocating Single-File Systems Followed by Matching Single-Cone Obturation

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Abstract: This study aimed to evaluate and compare the quality of matching single-cone obturation using three different single-file systems—WaveOne® Gold (Dentsply Sirona, Bensheim, Germany), Reciproc® blue (VDW GmbH, Munich, Germany), and Procodile® (Komet Medical, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany). The evaluation focused on the percentage of gutta-percha-filled areas (PGFAs), sealer-filled areas (PSFAs), and unfilled areas (PUAs) across three different sections of curved and straight root canals. Sixty extracted human teeth were categorized into six groups. Based on radiographically determined root canal curvature, thirty curved and thirty straight root canals were prepared using the single-file systems according to the manufacturers' instructions and obturated with matching gutta-percha cones using AH-Plus sealer. A total of 180 sections were evaluated digitally under the microscope and the results were statistically analyzed. The mean gutta-percha percentages for Reciproc® blue, Procodile®, and WaveOne® Gold were 83%, 82%, and 80%, respectively. No significant ($p > 0.05$) and relevant ($\eta_p^2 < 0.10$) differences were found in the proportion of form-fitting gutta-percha cones between the systems in all sections. Similarly, canal anatomy showed no significant influence ($p > 0.05$). Ex vivo, all three systems showed comparable filling quality in all sections of curved and straight canals. Therefore, it can be concluded that all three file systems, in combination with their corresponding gutta-percha points, might be reliable methods for root canal obturation. Reciproc® Blue, Procodile®, and WaveOne® Gold consistently achieved comparable obturation results across various root configurations and levels of the root canal.

Keywords: single-file systems; root canal obturation; single-cone obturation; reciprocating motion

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1. Introduction

Rotary and reciprocating instruments have revolutionized endodontic instrumentation by allowing a more efficient and faster root canal preparation [1]. Single-file systems maintain canal curvature, are associated with less instrument fractures, and allow a safe, fast, and more efficient root canal preparation than manual techniques [2,3]. Used in a carefully performed crown-down approach, both rotary and reciprocating single-file Ni-Ti instruments allow root canal preparations to be achieved with less straightening and acceptable apical debris extrusion [2]. Despite its benefits due to the increased flexibility of rotary Ni-Ti systems, fracture due to torsional and cyclic fatigue is still a concern with NiTi files [4,5].

Yared [3] introduced the concept of reciprocating motion of a motorized NiTi system based on a balanced force technique. These instruments cut dentin in a counter-clockwise

(CCW) direction and are immediately released in a clockwise (CW) reciprocating motion, rather than a rotating motion. Since the CW rotation is smaller than the CCW rotation, the instrument can advance into the root canal, reducing the risk of procedural errors (e.g., instrument fracture and canal transportation), preserving the original canal curvature effectively, and allowing the preparation of the majority of root canals without glide path preparation [6,7]. Nevertheless, the use of a glide path in a curved canal before the reciprocating single-file system is recommended due to the reduction in apical canal transportation [8,9]. There are several reciprocating single-file systems on the market, including WaveOne® Gold (Dentsply Sirona Deutschland GmbH, Bensheim, Germany), Reciproc® blue (VDW GmbH, Munich, Germany), and Procodile® (Komet Medical Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany), which demonstrate promising results in terms of reduced preparation time and a lower incidence of procedural errors [10–14]. Root canal preparation, coupled with a matching-taper single-cone obturation technique, offers a dependable means of shaping the root canal, resulting in fewer procedural errors and more satisfactory filling quality in terms of length and homogeneity, particularly in the apical third [15]. Obturated root canals using reciprocating file-matched single cones demonstrate comparable quality to other obturation techniques like lateral condensation, along with similar healing rates for apical lesions [16,17]. They also prove to be faster than traditional lateral condensation [18–20].

Therefore, the aim of this study was to compare three different single-cone obturation techniques regarding the portion of gutta-percha-filled areas (PGFAs), sealer-filled areas (PSFAs), and unfilled areas (PUAs) across three different sections of curved and straight canals using the three different reciprocating single-file systems—Reciproc® blue, Procodile®, and WaveOne®—for root canal preparation and their corresponding matching gutta-percha cones for single-cone obturation. The hypothesis to be evaluated was that the performance of the three different files systems differs significantly, resulting in variations in the percentage of gutta-percha, sealer, and unfilled areas across different sections and configurations of the root canals. The null hypothesis to be tested was that all three companies perform well and that the percentage of gutta-percha, sealer, and unfilled areas is the same in all groups.

2. Materials and Methods

2.1. General Study Design

In this ex vivo study, we included 60 root canals from single- and multi-rooted permanent teeth extracted from humans that did not undergo previous endodontic treatment and had completed root growth. Before the experimental procedure and over the entire experimental period, the teeth and prepared samples were stored in sterile, physiological 0.9% saline solution (Fresenius Kabi Deutschland GmbH, Bad Homburg, Germany) at room temperature. The study protocol and the use of extracted teeth received approval from the Ethics Committee of Martin-Luther-University Halle-Wittenberg, Halle, Germany (protocol number: 2024-023). All patients received verbal and written information on the study and signed consent forms prior to extraction.

2.2. Sample Selection

Teeth with root caries or root fractures as well as teeth that had undergone endodontic treatment or root apex resection were excluded. Single-rooted teeth were decoronated, while the roots of multi-rooted teeth were separated using diamond burs (Komet Dental Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany). This allows for an initial visual inspection of the root canal form. Subsequently, the initial apical file, working length, and root curvature were determined and illustrated radiographically using sterile size 10 and 15 K- and Hedstroem-Files (VDW GmbH, Munich, Germany). Furthermore, in order to minimize the influence of anatomical variations and root canal configurations, roots with an initial apical file greater than size 15 were excluded. The root curvature was determined using Schneider's method [21]. Canals with 0° to 5° and canals with 10° to 20°

were classified as straight and curved, respectively. Teeth with a root curvature exceeding 20° and those that presented two canals as well as oval or irregularly formed canals were also excluded from this study.

2.3. Sample Population

In this study, the obturation quality of three single-file systems and their corresponding gutta-percha points were compared using a single-cone obturation technique. Therefore, the sixty included roots were randomly classified into six groups based on root canal curvature and file system. Root canals were prepared with file size 25, since this size was available in all three reciprocating single-file systems. Accordingly, 20 roots (10 curved, 10 straight) were prepared per single-file system according to the manufacturers' instructions and filled with their prefabricated matching gutta-percha point and AH-Plus sealer (Dentsply Sirona Deutschland GmbH, Bensheim, Germany). Subsequently, these roots were examined in the apical, middle, and coronal section. This resulted in 30 samples per file system and configuration, and a total of 180 samples in the population.

2.4. Root Canal Preparation and Obturation

In each of the six groups, the canals were prepared with a reciprocating technique and a slow in-and-out pecking motion according to the manufacturers' instructions using a calibrated endodontic motor (VDW GmbH, Munich, Germany) with the variably tapered nickel–titanium Procodile®, WaveOne® Gold, and Reciproc® blue. Following a standardized protocol, a new single-file system from the respective groups was used for each canal, ensuring that the same conditions were present in all specimens. This involved alternating storage and irrigation using sterile 0.9% sodium chloride (NaCl) solution (Fresenius Kabi Deutschland GmbH, Bad Homburg, Germany), 3% sodium hypochlorite (NaOCl) solution (Aug. Hedinger GmbH & Co. KG, Stuttgart, Germany), and 20% Ethylendiamintetraacetat (EDTA) solution (Speiko—Dr. Speier GmbH, Bielefeld, Germany). Finally, a sonic-activated flush using EDDY™ (VDW GmbH, Munich, Germany) was performed [22]. During the root canal preparation, 15 mL of sodium hypochlorite and 5 mL of EDTA were used for each root canal simulating the clinical situation. The canals were then dried using paper points (Coltène/Whaledent GmbH, Altstätten, Switzerland).

Subsequently, the fully prepared canals were filled using the corresponding shape-congruent, prefabricated gutta-percha points and AH-Plus sealer (Dentsply Sirona Deutschland GmbH, Bensheim, Germany) using the single-cone obturation technique. The sealer was placed using a Lentulo spiral (VDW Root Filler, VDW GmbH, Munich, Germany). After the canal orifices were covered with Tetric Evo Flow® (Ivoclar Vivadent GmbH, Ellwangen, Germany) composites, the samples were stored in sodium chloride for at least 24 h before further processing to ensure the complete curing of the root filling.

2.5. Evaluation and Statistical Analysis

After hardening, the samples were embedded in Technovit® (Kulzer GmbH, Hanau, Germany) resin. In the next step, three slices (each 1 mm thin) were taken from each root canal at intervals of 3 mm starting from the apex (i.e., 3 mm, 6 mm, and 9 mm) using a diamond band saw (EXAKT Advanced Technologies GmbH, Norderstedt, Germany).

All the sections were analyzed and digitally measured with a fluorescence microscope (Compact, Model series BZ-X, KEYENCE Deutschland GmbH, Neu-Isenburg, Germany) to assess the proportion of areas filled with gutta-percha, sealer, and unfilled areas (Figure 1). Thereafter, the data were statistically analyzed using SPSS program Version 28.0. (IBM®, Ehningen, Germany). The normality of outcomes was evaluated by the Kolmogorov–Smirnov test. Two-way ANOVA at a 5% significance level was used to evaluate differences between the results of all groups. Since the frequency of filling quality did not have a normal distribution, we compared the quantitative outcomes by the Kruskal–Wallis and Mann–Whitney tests between three and two groups of study at a 5% significance level, respectively. The filling quality had normal distribution in straight or curved shaped

channels; thus, we compared this outcome between three companies by one-way ANOVA analysis at a 5% significance level.

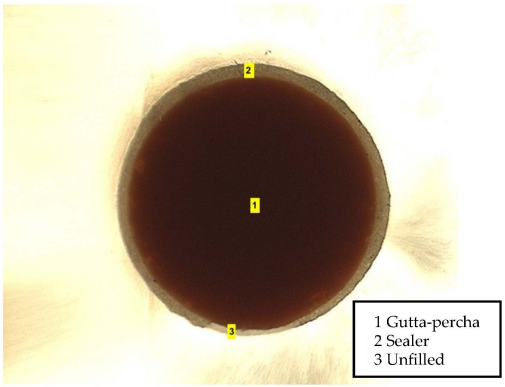

Figure 1. An apical section of a straight canal to visualize the performed evaluation technique. Gutta-percha-filled areas (1), sealer-filled areas (2), and unfilled areas (3) are visible. The calculation of the area size was performed using digital measurements under the microscope.

3. Results

3.1. General Result per File System

The examination (Figure 1) showed that the canals after single-cone obturation using the matching gutta-percha points were, in total, 82%, 17%, and 1% filled with gutta-percha, sealer, and voids, respectively, regardless of the file system, canal configuration, and canal area. According to the Kruskal–Wallis test, there was no significant difference in the portion of gutta-percha-filled areas (PGFAs, $p = 0.158$), sealer-filled areas (PSFAs, $p = 0.056$), and unfilled areas (PUAs, $p = 0.148$) between the three systems (Table 1).

Table 1. Evaluation of the filling quality between the three systems: SD = Standard Deviation (* Kruskal–Wallis Test).

		n	Mean (%)	SD	Variance Analysis (*p*) *
PGFA	WaveOne® Gold	60	80.3	9.03	0.158
	Procodile®	60	82.2	9.57	
	Reciproc® blue	60	83.4	5.65	
	Total	180	82.0	8.32	
PSFA	WaveOne® Gold	60	18.9	8.36	0.056
	Procodile®	60	16.8	8.96	
	Reciproc® blue	60	15.1	4.88	
	Total	180	17.0	7.73	
PUA	WaveOne® Gold	60	0.77	2.39	0.148
	Procodile®	60	0.93	2.05	
	Reciproc® blue	60	1.46	2.87	
	Total	180	1.05	2.46	

3.2. Results by Curvature

Regardless of the three different single-file and matching gutta-percha point systems and different root sections, the Mann–Whitney test shows no significant difference regarding PGFAs ($p = 0.358$), PSFAs ($p = 0.345$), and PUAs ($p = 0.309$) between the curved and straight canals processed with single-file systems size 25. However, straight canals have a slightly higher percentage of gutta-percha-filled areas, with 83% compared to curved canals with 81% (Table 2).

Table 2. Pooled results and comparison of PGFA, PSFA, and PUA between curved and straight canals (* Mann–Whitney U-Test).

		n	Mean (%)	SD	Variance Analysis (*p*) *
PGFA	curved	90	81.1	9.23	0.358
	straight	90	82.9	7.24	
	Total	180	82.0	8.32	
PSFA	curved	90	17.7	8.37	0.345
	straight	90	16.2	7.00	
	Total	180	17.0	7.73	
PUA	curved	90	1.19	3.01	0.309
	straight	90	0.92	1.77	
	Total	180	1.05	2.46	

Regarding the three different systems, the root canal filling composition (PGFA, PSFA, PUA) showed no significant differences between curved and straight root canals ($p > 0.05$, Table 3).

Table 3. One-way ANOVA to compare the three systems in straight and curved channels (* Kruskal–Wallis Test).

Configuration	Area	File System	n	Mean (%)	SD	Variance Analysis (*p*) *
curved	PGFA	WaveOne® Gold	30	78.9	10.6	0.404
		Procodile®	30	81.8	9.69	
		Reciproc® blue	30	82.6	6.90	
		Total	90	81.1	9.23	
	PSFA	WaveOne® Gold	30	20.1	9.28	0.218
		Procodile®	30	17.6	9.34	
		Reciproc® blue	30	15.4	5.50	
		Total	90	17.7	8.37	
	PUA	WaveOne® Gold	30	0.98	3.23	0.170
		Procodile®	30	0.56	1.53	
		Reciproc® blue	30	2.01	3.72	
		Total	90	1.19	3.00	
straight	PGFA	WaveOne® Gold	30	81.7	7.03	0.334
		Procodile®	30	82.6	9.61	
		Reciproc® blue	30	84.3	3.98	
		Total	90	82.9	7.24	
	PSFA	WaveOne® Gold	30	17.8	7.29	0.189
		Procodile®	30	16.1	8.65	
		Reciproc® blue	30	14.9	4.23	
		Total	90	16.2	7.00	
	PUA	WaveOne® Gold	30	0.55	1.08	0.477
		Procodile®	30	1.31	2.43	
		Reciproc® blue	30	0.90	1.50	
		Total	90	0.92	1.77	

3.3. Results per Canal Section

The results show that the coronal section is best filled with 85% gutta-percha, followed by the middle section with 82%, and the apical section with 79%. The middle section had the highest percentage of voids with 1.46%. Statistical analysis of the results shows no significant differences between the three systems with regard to PGFAs, PSFAs, and PUAs, neither in the apical section ($p = 0.193$, $p = 0.091$, and $p = 0.133$, respectively), nor in the

middle section ($p = 0.400$, $p = 0.85$, and $p = 0.223$, respectively), nor coronally ($p = 0.758$, $p = 0.840$, and $p = 0.513$, respectively, Table 4).

Table 4. Comparison of the three single-file systems in each section with one-way ANOVA, $p < 0.001$ (* Kruskal–Wallis Test).

Configuration	Area	File System	n	Mean (%)	SD	Variance Analysis (p) *
apical	PGFA	WaveOne® Gold	20	76.3	8.06	0.193
		Procodile®	20	79.4	10.6	
		Reciproc® blue	20	80.6	6.41	
		Total	60	78.8	8.59	
	PSFA	WaveOne® Gold	20	23.7	8.06	0.091
		Procodile®	20	19.6	9.44	
		Reciproc® blue	20	18.3	4.70	
		Total	60	20.5	7.87	
	PUA	WaveOne® Gold	20	0.00	0.00	0.133
		Procodile®	20	0.99	2.46	
		Reciproc® blue	20	1.13	2.87	
		Total	60	0.71	2.20	
middle	PGFA	WaveOne® Gold	20	79.2	10.5	0.400
		Procodile®	20	82.3	6.63	
		Reciproc® blue	20	83.9	4.74	
		Total	60	81.8	7.79	
	PSFA	WaveOne® Gold	20	19.7	8.40	0.085
		Procodile®	20	16.6	6.44	
		Reciproc® blue	20	14.0	4.17	
		Total	60	16.7	6.87	
	PUA	WaveOne® Gold	20	1.15	3.38	0.223
		Procodile®	20	1.10	2.02	
		Reciproc® blue	20	2.11	3.56	
		Total	60	1.46	3.05	
coronal	PGFA	WaveOne® Gold	20	85.4	5.75	0.758
		Procodile®	20	85.0	10.5	
		Reciproc® blue	20	85.8	4.57	
		Total	60	85.4	7.29	
	PSFA	WaveOne® Gold	20	13.5	5.09	0.840
		Procodile®	20	14.3	10.2	
		Reciproc® blue	20	13.1	4.24	
		Total	60	13.6	6.90	
	PUA	WaveOne® Gold	20	1.15	2.33	0.513
		Procodile®	20	0.71	1.68	
		Reciproc® blue	20	1.12	2.00	
		Total	60	0.99	2.00	

4. Discussion

In the present study, the performance of three reciprocating single-file systems was investigated ex vivo based on their obturation quality with a matching single-cone gutta-percha point. The stated hypothesis, that the obturation performance of the three different systems differs significantly, resulting in variations in the percentage of gutta-percha, sealer, and unfilled areas across different sections and configurations of the root canals, had to be rejected. The results of the present investigation revealed no significant impact of the used system, the standardized root canal curvature, or the examined root canal section. Therefore, the null hypothesis, that all three systems showed no significant differences in the composition, could be confirmed. This means that single-cone obturation using matching

gutta-percha points after root canal preparation with reciprocating single-file systems might help to achieve favorable results when focusing on the obturation composition.

The treatment steps for sample preparation, application of all materials, and the subsequent evaluation of the slices under the microscope were performed by one researcher, avoiding any influence by other persons. The endodontic treatment of the specimens followed a clinical recommended protocol including all clinical steps.

Prior studies suggest that root canal preparation followed by a matching-taper single-cone filling technique offers better shaping and root canal filling quality in the apical third compared to different cold and warm obturation methods, although results are less optimal in the central and cervical portions of the root canals [15,23]. The result of this study shows that the proportion of gutta-percha is highest in the coronal region at 85% and decreases apically (79%), while the proportion of sealer increases from coronal (14%) to apical (21%) regions.

This study shows that the middle area of the canal has the highest proportion of unfilled areas with 1.5%, which can be caused by irregular shapes of the canals or due to the sawing process under water cooling [24]. Additionally, these unfilled areas might be mainly created due the presence of debris after the instrumentation and irrigation of the root canal. The curved canals also have a larger proportion of cavities than the straight canals, although the difference is not significant. In this context, previous studies have shown that the AH-Plus exhibited higher leakage values than other gutta-percha containingand bioceramic sealers [25,26]. To improve the filling quality of the matching-taper single-cone technique in irregular canals, additional use of vertical and lateral condensation was recommended [15]. In our opinion, a combination of a shape-matched single-cone and isonormal gutta-percha points can also be an option for filling irregularly shaped canals. The bond strength of root canal fillings technique also appears to depend on the sealer [27]. The effect of irrigants on sealer bond strength was also investigated in prior studies. The epoxy resin-based AH-Plus sealer showed no impact in this context, whereas a methacrylate resin-based (RealSeal SE, SybronEndo, Orange, CA, United States) exhibited limitations [28]. Future studies may explore the influence of bioceramic sealers in this regard.

Although numerous studies regarding the composition of root canal fillings are available [29,30], the influence of obturation on clinical success is still discussed controversially and difficult to determine [17,31]. However, in terms of healing rates of periapical lesions, studies on single-cone obturation methods, using reciprocating file-matched single cones compared to other techniques for obturation, showed equivalent results regarding apical periodontitis healing after treatment [16,18]. So, regarding the clinical outcome, single-cone obturation might be comparable and seems to have no disadvantages compared to other techniques [17]. Future studies should compare the long-term outcomes of using reciprocating single-file systems in combination with matching gutta-percha points for obturation with regard to the healing rate of periapical lesions compared to other preparation and obturation techniques. The appropriate irrigation protocol, along with ultrasonic activation, can significantly impact these outcomes and should be carefully considered in this context [22,32]. The size of the periapical lesion is also highlighted as a crucial factor, as its growth significantly reduces the success of endodontic therapy [33].

A previous study, which compares variable- and constant-tapered single-cone gutta-percha obturation systems, shows that the area filled with gutta-percha is larger with the lateral condensation and single-cone technique with constant-tapered gutta-percha than with variable single-cone gutta-percha (ProTaper®, Reciproc®, WaveOne®) [34]. In another study that compares WaveOne Gold and Reciproc® Blue, it was found that Reciproc® Blue demonstrated superior adaptation and achieved ideal filling conditions more frequently, especially at 1 mm from the root apex and in the lingual wall. Despite observing larger spaces in the WaveOne® Gold group, these variances did not reach statistical significance [35]. In our study, no significant differences were found between WaveOne® Gold, Reciproc® Blue, and Procodile in terms of PGFA, PSFA, and PUA in different areas of the root canal. Reciproc® Blue shows a slightly better percentage of gutta-percha filling in all areas and in

both curved and straight canals. Among these three products, Wave One® Gold has the lowest PGFA apically (3 mm from the root apex) with 76%, but the greatest proportion of sealer with zero voids.

A previous study indicated that Reciproc® Blue is more resistant to cyclic fatigue than WaveOne® [36–38]. In our study, no instrument fractures were detected in any of the single-file systems across all study periods. All three single-file systems demonstrated reliable methods for root canal preparation.

This study adds to the understanding of single-file root canal preparations combined with single-cone obturation techniques, affirming their safety and efficacy in root canal treatment across all three manufacturers, although the limitations of an ex vivo study compared to a clinical study should be considered. Despite attempts at standardization, the diameter, the configuration of root canals, the anatomical variations, and the different tapers of the used single-file instrumentation systems and their corresponding gutta-percha cones can influence the results [39]. In order to minimize the influence of these anatomical variations and root canal configurations, roots with an initial apical file greater than size 15 were excluded in the present study.

Furthermore, differences in dimensions between the file instruments and the cones should be taken into account [40]. Since in this study samples had to be discarded and replaced after evaluation under the microscope due to the canal configuration or anatomical variations like oval- or c-shaped canals, possible impacts on the results should be considered [41]. Despite the results of the present study, the clinical impact of the observed composition of single-cone root canal obturation on the outcome and healing of pulpal and periapical disease remains uncertain. Therefore, we propose clinical studies in prospective or at least retrospective design to evaluate different single-file systems in future studies [42]. The fact that the teeth were collected at different times, from various dentists, and without consistent consideration of the patients' ages may introduce uncontrolled variability that could affect the consistency and reproducibility of the results.

5. Conclusions

Despite the limitations of an ex vivo study, it could be concluded that when focusing on the composition of the root canal fillings, the three reciprocating single-file systems used in combination with the corresponding gutta-percha points for single-cone obturation showed a high amount of gutta-percha-filled areas and similar results in all sections of curved and straight root canals.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and the use of extracted human teeth was approved by the Ethics Committee of Martin-Luther-University Halle-Wittenberg, Halle, Germany (protocol number: 2024-023, approved on 9 February 2024).

Informed Consent Statement: Informed consent was obtained from all subjects to use their teeth for dental laboratory research prior to extraction.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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