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Impact of cone system compatibility on single cone bioceramic obturation in canals prepared with variable taper NiTi rotary files

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Objective This study examined how system-matching gutta-percha (GP) cones in conjunction with calcium silicate-based sealers (CSBS) affect the sealing quality of canals prepared with variable taper nickel titanium (NiTi) files, using confocal laser scanning microscopy (CLSM) and micro-computed tomography (micro-CT).
Materials and methods Forty-eight extracted human mandibular premolars were instrumented using the ProTaper Ultimate and divided into four groups based on GP cone (system-matching vs. non-matching) and sealer type (PlanB vs. TotalFill). Obturation was performed using the single-cone technique. Sealers were mixed with Fluo-3 dye for CLSM visualization. Micro-CT was used to quantify voids and gaps, while CLSM evaluated sealer penetration area and depth at the coronal, middle, and apical thirds.
Results There were no significant differences in overall voids and gaps percentages between the cone systems ($p = 0.66$). System-matching cones however, significantly enhanced sealer penetration into dentinal tubules in terms of area, average, and maximum depth, especially in the apical third ($p \leq 0.001$). PlanB demonstrated greater penetration area than TotalFill ($p = 0.039$).
Conclusion The use of system-matching versus non-matching gutta-percha cones does not significantly affect the overall occurrence of voids and gaps in root canal fillings. However, system-matching cones improve sealer penetration into dentinal tubules, which differs among calcium silicate–based sealers. This emphasizes the importance of both cone fit and sealer selection in optimizing the quality of the single-cone obturation technique.
Clinical relevance In canals prepared with variable taper NiTi files, both the compatibility of gutta-percha cones and the properties of calcium silicate–based sealers play a key role in enhancing the quality of the single-cone obturation technique.

Keywords Gutta-percha, Bioceramic sealer, Calcium silicate-based sealers, Micro-CT, Confocal microscopy, Endodontic obturation, Sealer penetration, Root canal seal, Variable taper

The long-term success of endodontic therapy is largely influenced by effective disinfection and proper sealing of the root canal system. Given the complex and variable anatomy of root canals, achieving a reliable seal is essential. Root canal sealers are critical in forming a tight interface between gutta-percha and dentin, acting as a barrier against microbial infiltration and reducing the risk of reinfection and treatment failure[1,2].

Calcium silicate-based sealers (CSBS) have emerged as promising alternatives to traditional sealers such as epoxy resin-based sealers[3]. These materials contain bioactive compounds such as calcium silicates and

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phosphates, offering superior biocompatibility and bioactivity[4,5]. CSBS are hydrophilic and set in the presence of moisture within dentinal tubules, forming a hydroxyapatite-like mineral layer that chemically bonds with dentin. This enhances sealing ability and reduces microleakage[6]. Their availability in premixed, injectable forms has further increased their clinical adoption[7].

These properties have facilitated the widespread use of the single-cone (SC) obturation technique, particularly when combined with rotary nickel-titanium (NiTi) systems that create standardized canals compatible with matching gutta-percha cones. The SC technique simplifies obturation and offers success rates comparable to more complex methods[8], while eliminating the risk of heat-induced damage to the periodontal ligament[9,10].

In theory, the standardization of endodontic files and gutta-percha (GP) cones should enable interchangeability between products that share the same apical size and taper. However, multiple studies have reported significant inconsistencies in the actual dimensions of GP cones, with variations in both diameter and taper[11]. Interestingly, some research has found that certain gutta-percha cones align more closely with files from different manufacturers rather than their own corresponding systems[12,13].

These discrepancies largely stem from traditional rolling manufacturing methods, which lack the precision necessary to ensure dimensional consistency[14]. In response, precision injection molding has recently been introduced, enabling the production of GP cones with uniform shapes and tapers that closely match file geometries.

The clinical implications of these dimensional mismatches remain uncertain. Limited evidence exists regarding the impact of using non-matching GP cones on the quality of the obturation seal[15]. This becomes especially important when considering the significant differences in cost among GP cones. While more affordable alternatives may appear attractive, it is unclear whether their use without compatibility verification could compromise the quality of the obturation.

ProTaper Ultimate (Dentsply Sirona, Tulsa, OK, USA) is a next-generation, heat-treated NiTi system designed for use with Conform Fit GP cones (Dentsply International), which are manufactured using precision injection molding[16]. Studies have highlighted this system's improved flexibility, resistance to fatigue, and shaping efficacy while preserving canal anatomy[17–19].

This study aimed to evaluate the impact of using ProTaper Ultimate system-matching GP cones with different CSBS in the SC technique on root canal seal quality, assessed through sealer penetration and gap/void formation using micro-computed tomography (micro-CT) and confocal laser scanning microscopy (CLSM).

Materials and methods

This study was approved by the IRB Committee at Princess Nourah bint Abdulrahman University (IRB No: 24–0826). All methods of this ex-vivo study were performed in accordance with the Declaration of Helsinki guidelines. Sample size calculation was conducted using G*Power 3.1 software (Heinrich-Heine-Universität, Düsseldorf, Germany). At a significant level of $\alpha = 0.05$, with an estimated standard deviation of 0.05 and a power of 80%, a total sample size of 48 canals was determined. Forty-eight extracted human mandibular premolars were selected. Written informed consent was obtained from patients or legal guardians.

Inclusion criteria were straight, single, round canals with closed apices. Radiographs in both mesiodistal and buccolingual views were used to exclude canals with a buccolingual to mesiodistal ratio greater than 2 in the middle third. Exclusion criteria included immature apices, canal calcification, previous endodontic treatment, caries, cracks, internal or external resorption, and roots longer than 25 mm or shorter than 16 mm. The external surfaces were cleaned with ultrasonic instruments and stored in phosphate-buffered saline until use.

Root canal preparation

Access cavities were prepared using round and tapered fissure carbide burs. Canal patency was verified using a #15 K-file (Dentsply, Maillefer). Working length (WL) was established 1 mm short of the length where the file tip extruded beyond the apex. All canals were prepared by a single operator using ProTaper Ultimate rotary files up to size F3 (30/0.09 taper), following the manufacturer's protocol. Canals were irrigated with 2 mL of 5.25% NaOCl during and after each file, followed by a final rinse of 5 mL saline and 2 mL of 17% EDTA for 3 min. Final irrigation was done with 2 mL of saline, and canals were dried with paper points.

The teeth were randomly divided into two groups ($n = 24$). Group A was obturated with ProTaper Ultimate Conform Fit F3 cones (system-matching), and Group B with greater taper GP cones (30/0.06) from Meta Biomed (non-matching). Each group was further divided into two subgroups ($n = 12$) based on the sealer used: PlanB sealer (PlanB Dental, USA/Canada) and TotalFill sealer (FKG Dentaire, Switzerland). Sealers were mixed with 3 μL of Fluo-3, AM calcium indicator dye (Thermo Fisher Scientific) for CLSM visualization.

Obturation was performed using the SC technique by a single endodontist. After confirming tug-back and WL, sealer was delivered into the canals using the manufacturer's applicator, inserted 4 mm short of WL, and gradually withdrawn while dispensing. Access cavities were sealed with temporary material, and specimens stored at 37 °C with 100% humidity for one week.

Teeth were scanned using a Bruker SkyScan 1172 micro-CT scanner (Bruker, Belgium) with the following settings: 99 kV, 100 μA, 316 ms exposure, 20.73 μm voxel size, 0.6° rotation step, 360° rotation, frame averaging of 4, and random movement of 8. A Cu + Al filter was used. Images were reconstructed with N-Recon software (v1.6.9.4) using: ring artifact reduction level 5, 25% beam hardening correction, and Gaussian smoothing set to 2. CTAn software (v1.20.8.0) was used to analyze voids and gaps. Gaps were defined as sealer-dentin interface defects, and voids as internal defects within the sealer. Gaps and voids percentages were calculated for the whole canal and by thirds (coronal, middle, apical).

Specimens were sectioned at 2 mm, 6 mm, and 8 mm from the apex using a 0.3 mm low-speed saw at 200 rpm under water cooling, yielding 144 total sections. CLSM (LSM 5 Exciter, Zeiss, Germany) was used to analyze sealer penetration at 10 μm depth using a 5× lens (1024 × 1024 resolution). Excitation/emission wavelengths for fluorescein were 488/520 nm. Area and length of sealer penetration were measured at four standardized points (12, 3, 6, 9 o'clock) using ImageJ[19,20]. The maximum penetration depth was measured from the canal wall to the deepest dye point[21]. All measurements were duplicated by a single blinded operator and averaged.

SPSS software (v25; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Data normality was assessed with the Shapiro–Wilk test. The Mann–Whitney U test was used to compare voids and gaps percentages and sealer penetration area, while two-way ANOVA was used for average and maximum penetration lengths. Statistical significance was set at $p \leq 0.05$.

Results

There was no significant difference in the total volume or percentage of gaps, voids and total porosity (gaps + voids) between the system-matching and non-matching cone groups ($p = 0.66$) (Fig. 1). The coronal third exhibited the highest total porosity percentage regardless of cone type or sealer ($p < 0.0001$). In the system-matching group,

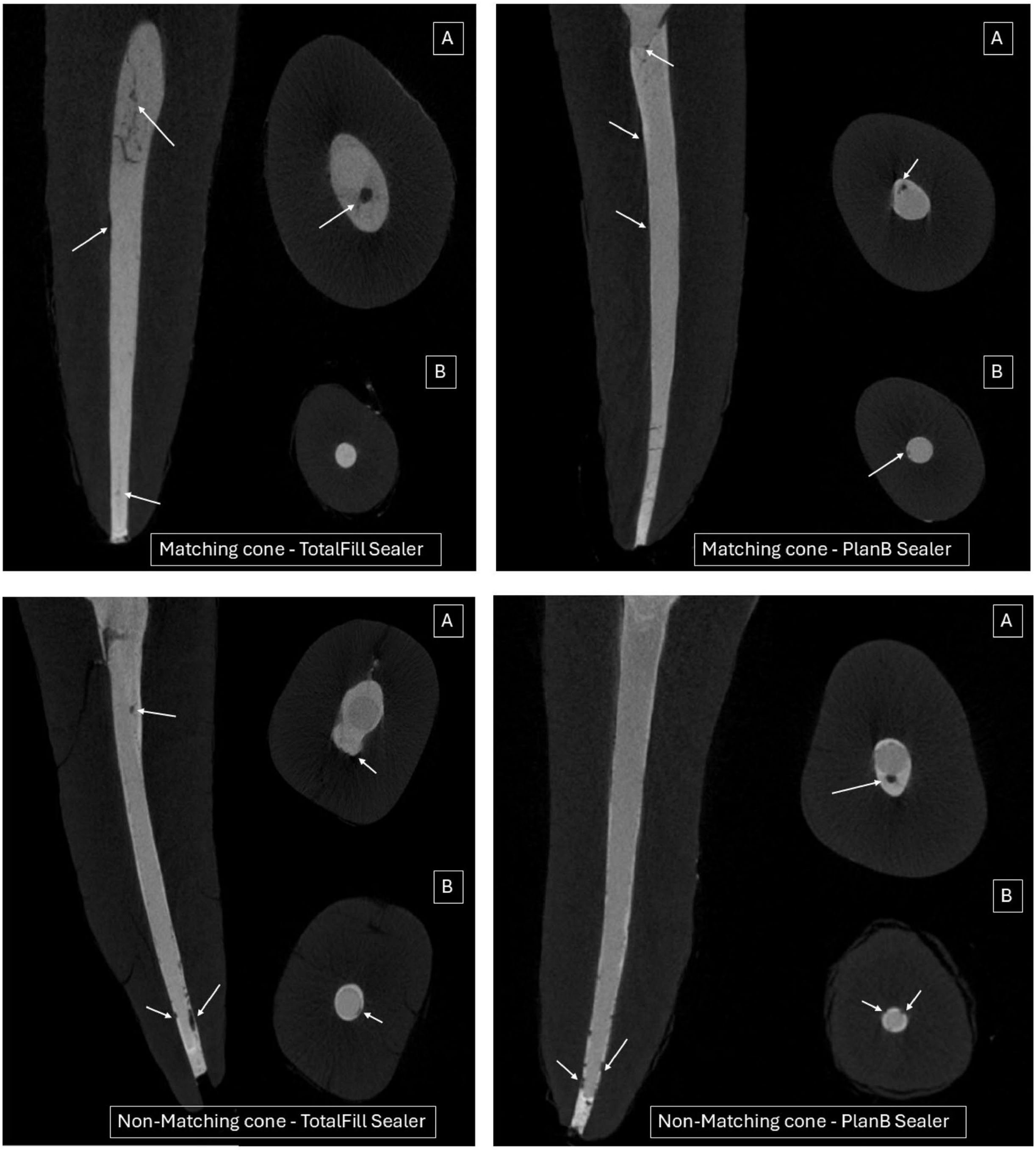

Fig. 1. Micro CT images for canals in the four experimental groups. (**A**) represents a section cut from the coronal thirds and (**B**) is an apical third section.

GP cone type	Sealer	n	Canal Third	Porosity (%) Median	Porosity (%) Mean ± SD	Porosity (%) CI Lower	Porosity (%) CI Upper	Void (%) Median	Void (%) Mean ± SD	Void (%) CI Lower	Void (%) CI Upper	Gaps (%) Median	Gaps (%) CI Lower	Gaps (%) CI Upper	Gaps (%) Mean ± SD
System matching	TF	12	Coronal	0.3	0.34 ± 0.21	0.2	0.48	0.2	0.24 ± 0.21	0.1	0.38	0.09	0.08	0.11	0.10 ± 0.02
			Middle	0.09	0.13 ± 0.13	0.05	0.21	0.002	0.04 ± 0.11	0.02	0.12	0.08	0.07	0.09	0.08 ± 0.01
			Apical	0.11	0.15 ± 0.11	0.08	0.22	0	0.03 ± 0.1	0.03	0.09	0.11	0.1	0.15	0.12 ± 0.03
	PB	12	Coronal	0.17	0.22 ± 0.23	0.11	0.67	0.05	0.13 ± 0.21	0.02	0.6	0.07	0.08	0.07	0.09 ± 0.03
			Middle	0.08	0.16 ± 0.19	0.02	0.35	0.003	0.08 ± 0.19	0.06	0.26	0.07	0.07	0.09	0.07 ± 0.01
			Apical	0.14	0.2 ± 0.12	0.04	0.32	0.02	0.08 ± 0.12	0.06	0.21	0.11	0.09	0.12	0.11 ± 0.02
Non-System matching	TF	12	Coronal	0.12	0.4 ± 0.4	0.07	0.37	0.05	0.3 ± 0.44	0	0.27	0.09	0.07	0.11	0.08 ± 0.01
			Middle	0.1	0.18 ± 0.25	0.03	0.28	0.008	0.09 ± 0.25	0.03	0.2	0.08	0.06	0.08	0.08 ± 0.01
			Apical	0.12	0.18 ± 0.22	0.12	0.19	0.002	0.07 ± 0.22	0	0.16	0.10	0.10	0.12	0.1 ± 0.02
	Pb	12	Coronal	0.13	0.17 ± 0.1	0.11	0.24	0.05	0.09 ± 0.11	0.02	0.17	0.07	0.06	0.09	0.07 ± 0.02
			Middle	0.08	0.11 ± 0,07	0.06	0.16	0.01	0.03 ± 0.08	0.01	0.09	0.07	0.06	0.08	0.07 ± 0.01
			Apical	0.1	0.09 ± 0.01	0.08	0.11	0.00	0.00 ± 0.008	0	0.01	0.09	0.08	0.1	0.09 ± 0.01

Table 1. Percentage of voids, gaps and total porosity (voids + gaps) of the root Canal filling in the different groups. * TF, TotalFill sealer; PB, PlanB sealer; SD, standard deviation; CI, confidence interval sealer.

GP cone type	Sealer	n	Penetration area% Median	Penetration area% Mean ± SD	Penetration area% 95% CI Lower	Penetration area% 95% CI Upper	Penetration area% *p*-value	Maximum penetration (mm) Mean ± SD	Maximum penetration (mm) 95% CI Lower	Maximum penetration (mm) 95% CI Upper	Maximum penetration (mm) *p*-value	Average penetration (mm) Mean ± SD	Average penetration (mm) 95% CI Lower	Average penetration (mm) 95% CI Upper	Average penetration (mm) *p*-value
System matching cone	TF	12	28.64^{a}	30.07 ± 13.42	24.77	35.39	0.02	1.68 ± 0.57^{a}	1.45	1.91	≤ 0.001	0.78 ± 0.27^{a}	0.67	0.88	≤ 0.001
	PB	12	34.01^{b}	39.74 ± 16.64	33.15	46.32		1.72 ± 0.42^{a}	1.55	1.89		0.83 ± 0.25^{a}	0.73	0.93	
System non-matching cone	TF	12	22.31^{c}	26.04 ± 16.92	19.34	32.73		1.05 ± 0.56^{b}	0.83	1.27		0.56 ± 0.34^{b}	0.43	0.70	
	PB	12	23.34^{d}	30.56 ± 19.14	22.98	38.13		1.19 ± 0.6^{b}	0.95	1.43		0.63 ± 0.35^{b}	0.49	0.77	

Table 2. Area and length of sealer penetration within the dentinal tubules in the different groups. *Significance was set a *p*-value of 0.05. *Different letters indicate statistical significance. *TotalFill sealer; PB, PlanB sealer; SD, standard deviation; CI, confidence interval sealer.

the median porosity was 0.23; 95% CI [0.19–0.38], while in the non-matching group it was 0.13; 95% CI [0.14–0.43]. The relatively wide confidence intervals in both groups indicate greater variability in this region compared to the middle and apical thirds. (Table 1).

Sealer penetration into dentinal tubules ranged from 1.05 mm to 1.72 mm in maximum depth, with penetration areas between 22% and 34% (Table 2). A significant difference in sealer penetration area was observed between the cone systems ($p = 0.02$), (Fig. 2). The mean penetration area for system-matching cones was 35%; 95% CI [30.6, 39.2], compared with 28.3% ; 95% CI [23.3–33.2] for non-matching cones. Although some overlap was present in the confidence intervals, the limits consistently favored greater penetration with system-matching cones. This difference was pronounced in the apical third ($p = 0.022$). Additionally, both maximum and average sealer penetration lengths were significantly greater in the system-matching groups ($p \leq 0.001$). (Table 2).

PlanB sealer achieved a significantly greater penetration area than TotalFill ($p = 0.039$), with a mean of 35.1% ; 95% CI [30.1–40.1] compared to 28.% for TotalFill (95% CI [23.9, 32.2]). Although the confidence intervals show partial overlap, the higher lower bound for PlanB compared to TotalFill suggests a consistent advantage in penetration area for PlanB. Both sealers showed relatively narrow confidence intervals, indicating good precision in the estimates. However, no statistically significant differences were found between sealers for maximum penetration length ($p = 0.33$) or average penetration length ($p = 0.45$).

Discussion

This study is the first to evaluate the impact of using system-matching gutta-percha (GP) cones with different calcium silicate-based sealers (CSBS) on seal integrity in the single-cone (SC) obturation technique. Micro-computed tomography (micro-CT) analysis revealed no significant difference in total filling porosity (gaps + voids) between system-matching and non-matching cones. Across all groups, the percentage of voids and gaps was consistently low, and statistical analysis confirmed that cone compatibility had no significant influence on overall porosity. These findings are consistent with previous studies conducted on round, straight canals, which reported similar results using comparable canal geometries[22,23]. Additionally, research comparing standardized and greater taper cones also found no notable differences in canal total porosity across different cone systems[24].

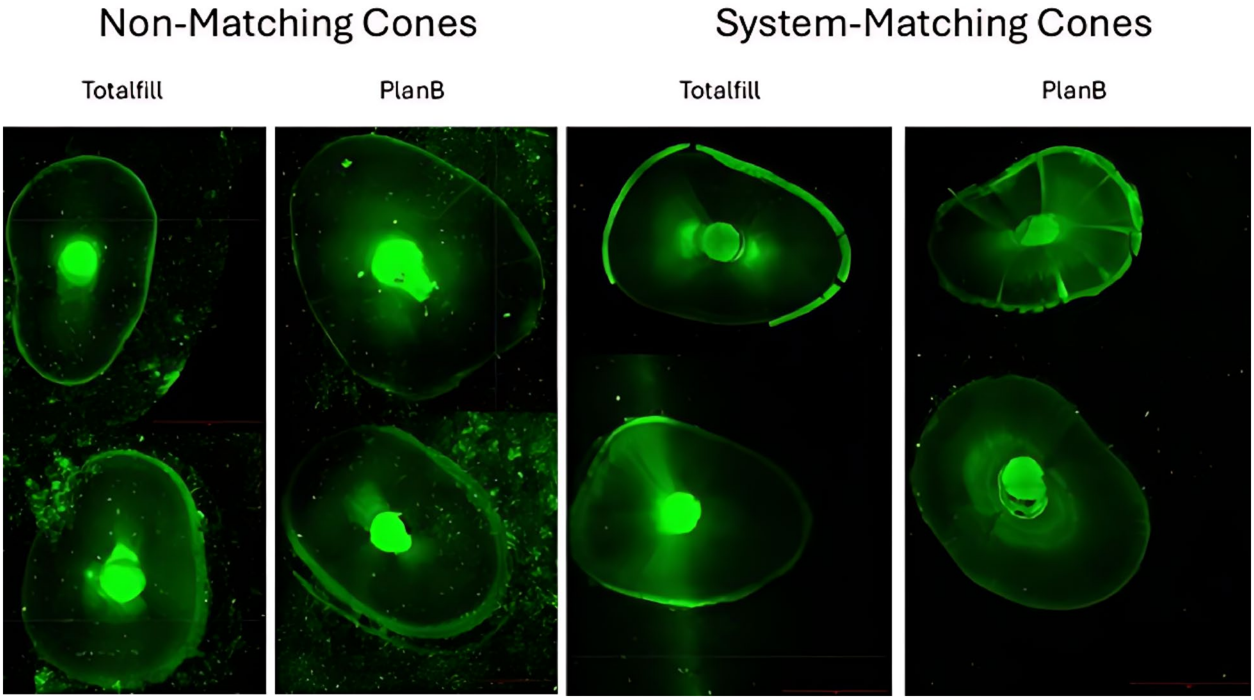

Fig. 2. Confocal laser scanning microscopic images showing the area of sealer penetration in the dentinal tubules within the different groups.

However, another study has shown that non-standardized cones may result in more apical gaps when compared to system-matching cones[24], underscoring the variability in results depending on canal anatomy and materials used.

A higher incidence of porosity was noted in the coronal third of the canal system, aligning with previously published data[22,23,25]. Conversely, the apical third consistently showed lower porosity. Given that the apical third plays a pivotal role in long-term treatment success, the reduced porosity observed in this region is a clinically relevant finding.

Neither cone type nor sealer had a significant effect on the formation of internal voids within the filling material itself, corroborating findings from prior investigations involving a variety of sealers and cone systems[24,25].

While micro-CT is a powerful non-destructive tool for evaluating voids and gaps within root canal fillings, it has inherent resolution limitations. In this study, the voxel size was 20 microns, as a result, micron-scale interfacial gaps may fall below the resolution threshold and remain undetected[23]. Dentinal tubules are highly susceptible to bacterial invasion and colonization, often forming reservoirs for both single and multispecies biofilms[26]. Effective sealer penetration into these tubules can enhance the mechanical retention of the obturation, entomb residual microorganisms, and serve as a physical barrier to reinfection, thereby contributing to the long-term success of endodontic treatment[27]. While assessing sealer penetration provides valuable insight into the suitability of endodontic sealers for clinical application, alone it does not guarantee improved long-term outcomes[28].There is no evidence to confirm that alone it translates into superior seal integrity and improved success rates.

The current study demonstrated that system-matching cones significantly improved sealer penetration into dentinal tubules—in terms of area, average depth, and maximum depth—particularly in the apical third. In the SC technique, the gutta-percha cone acts as a hydraulic piston, distributing sealer throughout the canal. System-matching cones, especially those manufactured using precision injection molding, may facilitate more effective hydraulic distribution, improving sealer adaptation in anatomically challenging regions.

Prior studies have shown that the apical portion of the canal often exhibits the least sealer penetration due to reduced tubule density and limited irrigant access[21,29,30]. However, the enhanced penetration observed in our study with system-matching cones suggests that a precise fit may compensate for these anatomical limitations.

It is worth noting that sealer penetration and interfacial adaptation are not necessarily correlated. A sealer may penetrate deeply into tubules without forming an optimal interface with the canal wall[31]. In this study, PlanB and TotalFill sealers were compared. TotalFill, also marketed as EndoSequence® BC Sealer™, has an established record and is widely used in SC obturation[32]. According to a recent systematic review, it is the most extensively studied CSBS regarding tubule penetration[28].

PlanB, a newer CSBS, incorporates bioglass to support regenerative healing—aligning with modern goals for biologically driven endodontic therapy. According to the manufacturer, PlanB exhibits lower solubility (< 1.0%), enhanced washout resistance, and a faster setting time of one hour due to its calcium aluminate-based composition[33]. To date, no independent research has been published on this sealer, making the current findings novel.

The superior penetration achieved with PlanB suggests that physicochemical properties—including viscosity, flow characteristics, working and setting times, solubility, surface tension, and chemical composition—directly influence a sealer's capacity to infiltrate dentinal tubules[28,34]. Given that instrumentation, irrigation, and obturation techniques were standardized in this study, the observed differences likely reflect intrinsic material behavior.

CLSM was employed in this study to visualize sealer infiltration accurately. This method minimizes artifacts and dehydration, allowing detailed, high-contrast imaging regardless of sample thickness. Unlike rhodamine B, which may bind to residual moisture and falsely suggest sealer penetration, the Fluo-3 dye used in this study binds specifically to calcium ions within CSBS, enhancing the reliability of the observations[35]. However, differences in chemical composition of CSBS can affect how much calcium is available for the dye to bind to. The presence of bioglass or calcium aluminate in PlanB may alter calcium ion release leading to a systematic bias in measured penetration area and depth[36,37]. The superior penetration achieved with PlanB suggests that physicochemical properties—including viscosity, flow characteristics, working and setting times, solubility, surface tension, and chemical composition—directly influence a sealer's capacity to infiltrate dentinal tubules[32,35]. Given that instrumentation, irrigation, and obturation techniques were standardized in this study, the observed differences likely reflect intrinsic material behavior.

ProTaper Ultimate F3 cones used in this study carry a 0.09 taper in their apical portion while the selected non-matching cones had a taper of 0.06. This taper mismatch could not be avoided due to the variable taper of the canal preparation. The ProTaper Ultimate file system features a progressively variable taper, with a larger taper in the apical region that gradually decreases toward the coronal portion of the canal. As a result, alternative non-matching cones with a closer apical taper (e.g., 0.08) were not suitable; although they might have provided a better apical fit, their larger coronal diameter lead to premature binding in the coronal third and prevented them from reaching full working length. Using cones with reduced conicity may have limited the hydraulic distribution and penetration of the sealer. Therefore, the observed differences in sealer penetration may reflect not only the matching status of the cones, but also the dimensional taper mismatch. This investigation focused on straight, round canals to maintain anatomical consistency. Such configurations facilitate uniform canal shaping and better exposure of dentinal tubules. However, this controlled setup may limit the generalizability of the results. More complex canal morphologies—such as curved, oval, or bifurcated canals, or those with open apices—could compromise cone adaptation and affect both sealer distribution and filling quality. Future research should explore these clinical scenarios to validate the findings in anatomically challenging situations commonly encountered in practice.

Canal obturation in this study was performed by a single experienced endodontist. While this approach enhances standardization and minimizes variability in technique, it also introduces a potential limitation regarding external validity. Consequently, outcomes observed in this study might differ when performed by clinicians with varying levels of experience, which is also a point that may be addressed in future studies.

Another limitation is the lack of formal intra-operator reliability assessment. Although duplicate measurements were averaged to reduce random error, this does not confirm measurement consistency. Future studies should provide a more robust assessment of intra-operator reliability.

To date, no independent studies have been published on the PlanB sealer, making the current findings novel. However, further research is warranted to validate these results and fully understand the material's performance and clinical implications.

Conclusion

Within the limitations of this study, the findings suggest that in straight round root canals, the use of system-matching versus non-matching gutta-percha cones does not significantly affect the overall presence of voids and gaps in root canal fillings.

On the other hand, system-matching cones significantly enhanced sealer penetration into dentinal tubules. These findings underscore the importance of using well-fitted gutta-percha cones in the single-cone obturation technique and suggest that both mechanical compatibility and the chemical properties of calcium silicate-based sealers are essential for achieving an optimal seal.

Data availability

The datasets generated and analyzed in this study are available from the corresponding author upon request.

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Author contributions

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
The study received an approval exemption, according to the Internal Review Board at Princess Nourah bint Abdulrahman University (IRB no. 24–0826).

Informed consent
Written informed consent was obtained from patients or legal guardians.

Additional information
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