Original Research

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Impact of taper on foraminal enlargement and deformation in curved mesial canals of mandibular molars: in vitro study

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Abstract

AIM. This study aimed to evaluate the influence of different instrument tapers on the enlargement and morphological alterations of the apical foramen in curved mesial canals of mandibular molars.

MATERIALS AND METHODS Forty mesial canals from mandibular molars with moderate curvature were randomly allocated into five experimental groups ($n = 8$) based on the taper of the final instrumentation file: 25/.01, 25/.03, 25/.04, 25/.05, and 25/.06. Irrigation was performed with 2.5% sodium hypochlorite and 17% EDTA. The foraminal area and shape were assessed using stereomicroscopy (40x magnification) and ImageJ before and after preparation. Non-parametric tests (Dunn and Wilcoxon) were used for intragroup and baseline comparisons. Parametric tests (ANOVA and Tukey) were applied to compare the percentage of foraminal enlargement between groups, and the Chi-square test evaluated alterations in foraminal shape. The significance level was set at 5% ($\alpha = 0.05$).

RESULTS. All tapers resulted in a statistically significant increase in the apical foraminal area ($p < 0.05$). The 25/.01 and 25/.06 instruments produced the greatest percentage increases in area (85.09% and 92.76%, respectively), whereas the 25/.03 and 25/.05 instruments promoted the most conservative enlargement (39.43% and 32.41%, respectively). However, no statistically significant difference was observed among the groups regarding the alteration of the foraminal shape ($p > 0.05$).

CONCLUSIONS. The taper and the cross-section design of the endodontic instrument significantly influenced the apical foraminal enlargement but did not have a significant effect on the preservation of its original morphology. Instruments with .03 and .05 tapers resulted in the most conservative foraminal preparation.

Keywords: apical foramen, canal preparation, endodontics, NiTi instruments

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Влияние конусности инструмента на расширение и деформацию апикального отверстия в искривленных мезиальных каналах нижних моляров: исследование in vitro

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Резюме

ЦЕЛЬ. Оценить влияние различных значений конусности эндодонтических инструментов на степень расширения и морфологические изменения апикального отверстия в искривленных мезиальных каналах нижних моляров.

МАТЕРИАЛЫ И МЕТОДЫ. В исследование были включены 40 мезиальных каналов нижних моляров с умеренной степенью искривления, которые методом случайной выборки были распределены на пять экспериментальных групп ($n = 8$) в зависимости от конусности последнего использованного инструмента: 25/.01, 25/.03, 25/.04, 25/.05 и 25/.06. Ирригацию проводили с использованием 2,5% раствора гипохлорита натрия и 17% раствора ЭДТА (этилендиаминтетрауксусной кислоты). Площадь и форма

апикального отверстия оценивались до и после инструментальной обработки с помощью стереомикроскопии (увеличение ×40) и программы ImageJ. Для внутригрупповых сравнений и сравнения с исходными значениями применяли непараметрические критерии Данна и Вилкоксона. Для сравнения процентного увеличения площади апикального отверстия между группами использовали параметрические методы (дисперсионный анализ ANOVA и критерий Тьюки), а изменения формы отверстия оценивали с помощью критерия χ^2 (хи-квадрат). Уровень статистической значимости был принят равным 5% (α = 0,05).
РЕЗУЛЬТАТЫ. Применение инструментов всех исследуемых конусностей сопровождалось статистически значимым увеличением площади апикального отверстия (p < 0,05). Наибольшее относительное увеличение площади наблюдалось при использовании инструментов 25/.01 и 25/.06 (85,09% и 92,76% соответственно), тогда как инструменты 25/.03 и 25/.05 обеспечивали наиболее щадящее расширение апикального отверстия (39,43% и 32,41% соответственно). При этом статистически значимых различий между группами по степени изменения формы апикального отверстия выявлено не было (p > 0,05).
ЗАКЛЮЧЕНИЕ. Конусность и конструкция поперечного сечения эндодонтического инструмента оказывают существенное влияние на степень расширения апикального отверстия, однако не оказывают статистически значимого влияния на сохранение его исходной морфологии. Наиболее консервативную подготовку апикального отверстия обеспечивали инструменты с конусностью .03 и .05.

Ключевые слова: апикальное отверстие, препарирование корневого канала, эндодонтия, никель-титановые инструменты

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INTRODUCTION

Endodontics plays a fundamental role in preserving the health of periradicular tissues, treating and preventing pulpal infections. For successful endodontic treatment, the effective elimination of microorganisms and the establishment of an environment favorable for tissue repair are fundamental [1]. This is primarily accomplished through adequate chemomechanical preparation of the root canal system, a critical process combining mechanical instrumentation with chemical irrigation [2].

The mesial canals of mandibular molars present a significant challenge in endodontics due to their complex anatomy and frequent curvature [3]. The selection and design of endodontic instruments are critical determinants of both cleaning efficacy and the preservation of root canal integrity. Also, the instrument taper can directly influence cutting efficiency, flexibility, and the extent of dentin removal [4]. While larger-taper instruments enhance debridement, they also increase the risk of structural weakening, whereas smaller tapers offer greater flexibility but may limit disinfection [5].

Despite the importance of apical foramen enlargement in removing debris and biofilm at the cement canal, the use of instruments with different tapers can, under certain conditions, lead to excessive enlargement or, more critically, foraminal deformation [6; 7]. Such alterations can compromise apical sealing ability and, consequently, the prognosis of endodontic treatment [8].

The clinical adoption of nickel-titanium (NiTi) instruments is largely justified by their enhanced safety profile, which reduces the risk of procedural errors such as canal transportation, separation and ledge formation. Over the years, NiTi systems have evolved through continuous improvements in design, including cross-sectional geometry, taper, and tip configuration, as well as through the development of advanced thermally treated alloys [9]. Among these, the Logic file system (Bassi / Easy Equipamentos, Belo Horizonte, Brazil), manufactured from NiTi controlled-memory wire, features a range of tips and tapers, with cross-sectional designs strategically allocated according to taper: a double-helix for .03, .05, and .06 tapers; a triple-helix for the .04 taper; and a quadruple-helix for the .01 taper instruments.

This study acknowledges that both taper and cross-sectional design (which varies within the Logic system based on taper) influence outcomes. By testing these instruments, the study indirectly contributes data on how these combined design elements of the Logic system affect apical preparation, adding to the understanding of this instrument's characteristics.

Given the critical balance required between effective debridement and the preservation of apical anatomy, a comparative evaluation of different instrumentation tapers within the same file system is warranted. Therefore, the aim of this study was to evaluate the influence of different tapers (.01, .03, .04, .05, and .06) of the Logic file system on the enlargement and morphological alteration of the apical foramen in curved mesial canals of mandibular molars. The null hypothesis tested was that there would be no statistical difference between the tested groups regarding (i) foramen enlargement and (ii) foraminal deformation.

MATERIALS AND METHODS

This laboratory investigation adhered to the PRILE 2021 guidelines (Fig. 1) [10] and all experimental protocol were approval by the Human Research Ethics Committee (CAAE – 88107825.6.0000.5417), adhering to the Helsinki Declaration's ethical standards. The patients signed a donation and informed consent form for the use of the teeth in this study.

RATIONALE / JUSTIFICATION
This study was conducted to scientifically evaluate the foraminal enlargement and deformation of mesial canals of mandibular molars

↓

AIM
To evaluate the influence of different instrument tapers on the enlargement and morphological alterations of the apical foramen in curved mesial canals of mandibular molars

HYPOTHESIS
There would be no difference between the tested groups regarding (i) foramen enlargement and (ii) foraminal deformation

↓

ETHICAL APPROVAL
The present study was registered and ethically approved by the Human Research Ethics Committee (CAAE 88107825.6.0000.5417), adhering to the Helsinki Declaration's ethical standards

↓

SAMPLES
Forty mesial canals of mandibular molars

↓

EXPERIMENTAL END CONTROL GROUPS
Group 1: 25/.01 • Group 2: 25/.03 • Group 3: 25/.04
Group 4: 25/.05 • Group 5: 25/.06

↓

OUTCOME(S) ASSESSED
Foraminal enlargement and deformation

↓

METHOD USED TO ASSESS THE OUTCOMES
Stereomicroscopy (40x magnification)

↓

RESULTS
All tapers resulted in a statistically significant increase in the apical foraminal area ($p < 0.05$). The 25/.01 and 25/.06 instruments produced the greatest percentage increases in area (85.09% and 92.76%, respectively), whereas the 25/.03 and 25/.05 instruments promoted the most conservative enlargement (39.43% and 32.41%, respectively). However, no statistically significant difference was observed among the groups regarding the alteration of the foraminal shape ($p > 0.05$)

↓

CONCLUSION(S)
Instruments with .03 and .05 tapers resulted in the most conservative foraminal preparation

↓

FUNDING DETAILS
None

Fig. 1. PRILE flowchart

Рис. 1. Блок-схема PRILE

Sample Size Calculation

Sample size calculation was performed using G*Power 3.1.9.4 software (Heinrich Heine University, Dusseldorf, Germany) for a significance level of 5% and a power of 80% with the analysis of variance model. The result indicated the need for a minimum of 8 root canals per group.

Tooth Selection

Forty mesial canals from extracted human mandibular molars, obtained for reasons unrelated to this study, were selected. The teeth were stored in a biorepository in 0.1% thymol solution until the start of the research.

Inclusion Criteria

The inclusion criteria comprised mandibular molars with complete root formation and mesial roots exhibiting independent canals. Only teeth with mesial root canal curvatures ranging between 20° and 30°, as determined by Schneider's method [11] and without evidence of previous endodontic treatment, resorption, cracks, fractures, or caries were selected.

Teeth were excluded from the study in cases of root dilaceration, pathological internal or external resorption, pulp canal calcification or obliteration, an open apex, or the presence of more than two root canals in a mesial root.

Initial Preparation

The coronal portions of the teeth were sectioned using a low-speed handpiece with a carborundum disc to standardize all specimens to a length of 18 mm, as verified by a digital caliper. Endodontic access cavities were prepared with #1012 and #1011 spherical burs in a high-speed handpiece. The working length was established at the apical foramen by introducing a #10 K-file (Target, Bassi / Easy Equipamentos, Belo Horizonte, Brazil) until its tip was visible under an operating microscope at 8x magnification.

Each tooth was individually embedded in high-precision impression material (3D, Angelus, Londrina, Brazil) with access cavities facing down, to allow for precise repositioning during pre- and postoperative scanning. The initial condition of the apical foramen was documented using a stereomicroscope (Stemi 2000C, Carl Zeiss, Jena, Germany) at 40x magnification. Digital images were captured with AxioVision 4.8 software (Carl Zeiss), and the initial foraminal area (A0) was measured from these images using ImageJ software (National Institutes of Health, Bethesda, MD, USA).

Specimen Distribution and Root Canal Instrumentation

The specimens were randomly assigned (random.org) into five experimental groups (n = 8 per group) according to the taper of the Logic instrument used for final preparation: Group 1: 25/.01; Group 2: 25/.03; Group 3: 25/.04; Group 4: 25/.05; Group 5: 25/.06. All procedures were performed by a single experienced operator.

A standardized instrumentation sequence was followed. Cervical preparation was initially performed with an S2 15/.10 instrument (Bassi / Easy). This was followed by preparation with an S2 15/.05 instrument (Bassi / Easy) at 350 rpm and 1.0 N·cm torque up to the WL. Finally, the experimental Logic instrument for each group was used at 400 rpm and 1.5 N·cm torque to the WL. Each instrument was used to prepare a single mesial canal.

Throughout the instrumentation sequence, the root canals were irrigated following each instrument removal. The flutes of each instrument were cleaned with sterile gauze. A total of 30 mL of 2.5% sodium hypochlorite (NaOCl) was used as the primary irrigant per tooth. Upon completion of the mechanical preparation, a final irrigation protocol was conducted, consisting of three alternating cycles of 2.5% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA).

Post-Instrumentation Evaluation

Following instrumentation, the teeth were remounted in their silicone molds, and the apical foramina were re-photographed under stereomicroscopy at 40x magnification to determine the final foraminal area (A1). The percentage of foraminal enlargement (PFE) was calculated for each specimen using the formula:

$$\mathrm{PFE}\,(\%) = \frac{\mathrm{A1} - \mathrm{A0}}{\mathrm{A0}} \times 100.$$

Morphological analysis of the apical foramen was performed on the post-operative images by measuring the largest and smallest diameters. Based on the difference between these diameters, the foramina were classified into one of three categories, adapted from Marroquim and Al-Sayed [12]:

– circular: difference < 0.02 mm;
– oval: difference between 0.02 mm and 0.06 mm;
– deformed: difference > 0.06 mm.

This classification enabled a comparative assessment of foraminal shape before and after the procedure.

Statistical Analysis

Data were tested for normality using the Shapiro-Wilk test. Due to the absence of normality in baseline and intragroup comparisons, non-parametric Kruskall-Wallis / Dunn and Wilcoxon tests were employed. For comparison between groups regarding the percentage of area increase, data showed normality, so ANOVA and Tukey tests were applied. Additionally, a Chi-square test was applied to evaluate the proportion of foraminal alteration between groups. A significance level of 0.05 ($\alpha = 5\%$) was adopted for all analyses.

RESULTS

The analysis of data distribution revealed no statistically significant differences in initial foraminal diameters between the taper groups ($p > 0.05$), confirming the homogeneity of the groups before preparation (Table 1).

Foraminal Enlargement

For all tapers, a statistically significant difference was observed between the foraminal areas before and after preparation ($p < 0.05$). This means that instrumentation with any of the tested tapers resulted in foraminal enlargement (Table 1).

Percentage Foraminal Enlargement

The instrument taper significantly influenced the PFE ($p < 0.05$). The mean PFE values were 85.09% for the 25/.01 group, 39.43% for 25/.03, 68.53% for 25/.04, 32.41% for 25/.05, and 92.76% for the 25/.06 group. Post-hoc analyses revealed that the 25/.01 instrument produced a significantly greater enlargement than the 25/.05 ($p = 0.020$). Furthermore, the 25/.06 instrument resulted in a significantly greater enlargement than both the 25/.03 ($p = 0.018$) and the 25/.05 ($p = 0.006$) groups. No other inter-group comparisons were statistically significant (Table 2). The 25/.04 instrument did not differ significantly from any of the other four groups.

Morphological Analysis

No statistically significant differences in foraminal morphology or the incidence of deformation were observed among the experimental groups ($p > 0.05$) (Table 3). The distribution of apical foramen configurations following mechanical preparation is presented in Figure 2. Figure 3 presents post-preparation foraminal aspects produced and illustrates the classification performed.

Table 1. Descriptive statistics and intragroup comparison of foraminal area before and after instrumentation with Logic files of different tapers

Таблица 1. Описательная статистика и внутригрупповое сравнение площади апикального отверстия до и после инструментальной обработки файлами Logic с различной конусностью

Group $n = 8$	Foraminal area before preparation (mm²)		Foraminal area after preparation (mm²)		*p*-value
	mean (SD)	median	mean (SD)	median	
25/.01	0.1158 (0.0329)[a]	0.1150	0.2063 (0.0427)	0.2095	0.0078
25/.03	0.1410 (0.0145)[a]	0.1415	0.1974 (0.0301)	0.2090	0.0078
25/.04	0.1278 (0.0224)[a]	0.1195	0.2091 (0.0244)	0.2070	0.0078
25/.05	0.1414 (0.0207)[a]	0.1430	0.1883 (0.0394)	0.1875	0.0078
25/.06	0.1115 (0.0285)[a]	0.1015	0.2056 (0.0248)	0.2130	0.0078

Note. Same letters in the same column indicate that there was no significant difference.
Примечание. Одинаковые буквы в одном столбце указывают на отсутствие существенной разницы.

Table 2. Percentage increase in foraminal area after instrumentation with Logic files of different tapers

Таблица 2. Процентное увеличение площади апикального отверстия после инструментальной обработки файлами Logic с различной конусностью

Group	Mean % Increase (SD)
25/.01	85.09 (40.99)[a]
25/.03	39.43 (11.48)[b]
25/.04	68.53 (35.71)
25/.05	32.41 (13.01)[b]
25/.06	92.76 (44.67)[a]

Note. Same letters in the same column indicate that there was no significant difference.
Примечание. Одинаковые буквы в одном столбце указывают на отсутствие существенной разницы.

Table 3. Alteration of foraminal morphology after instrumentation with Logic files of different tapers

Таблица 3. Изменение морфологии апикального отверстия после инструментальной обработки файлами Logic с различной конусностью

Group	Proportion of maintained cases	Proportion of altered cases
25/.01	0.75	0.25
25/.03	0.625	0.375
25/.04	0.875	0.125
25/.05	0.625	0.375
25/.06	0.40	0.60

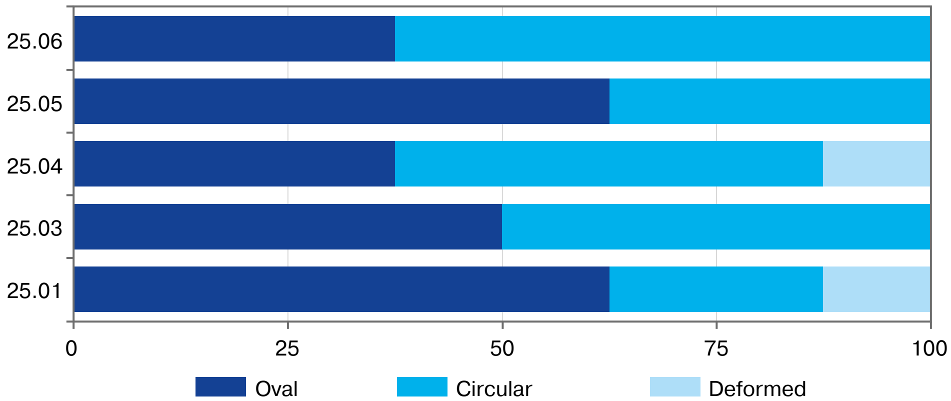

Fig. 2. Graphical representation of the occurrence of apical foramen configurations after root canal instrumentation

Рис. 2. Распределение конфигураций апикального отверстия после инструментальной обработки корневых каналов

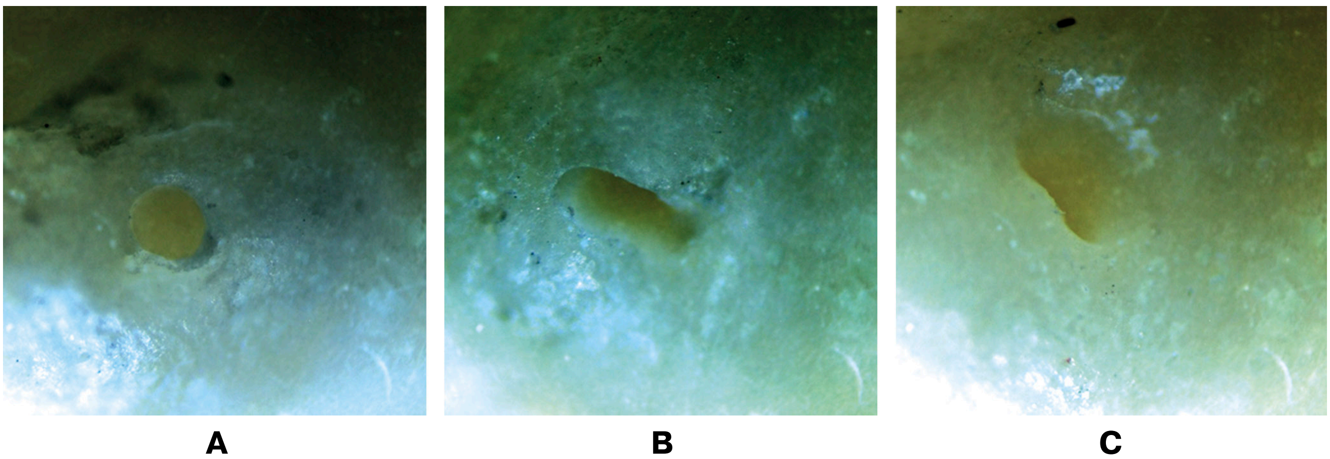

Fig. 3. Apical foramen configuration examples after mechanical preparation using different techniques and working lengths: *A* – circular; B – oval; *C* – deformed

Рис. 3. Примеры конфигурации апикального отверстия после механической обработки с использованием различных методик и рабочей длины: *A* – круглая; B – овальная; *C* – деформированная

DISCUSSION

The present study demonstrated that the taper of the NiTi CM files significantly influences apical foraminal enlargement in the curved mesial canals of mandibular molars. This finding aligns with a fundamental objective of chemomechanical preparation: to create adequate apical patency. Such enlargement is critical to facilitate the debridement of the apical third, as it enhances the penetration and efficacy of irrigating solutions and promotes the removal of debris and biofilm [13]. Furthermore, an adequately prepared foramen is a prerequisite for achieving a fluid-tight three-dimensional obturation [14].

A key finding of this investigation was the significant variation in foraminal enlargement, which appears to be a function of both instrument taper and its corresponding cross-sectional design. The Logic 25/.01 and 25/.06 instruments produced the most substantial percentage increases in foraminal area (85.09% and 92.76%, respectively), whereas the 25/.03 and 25/.05 instruments yielded the most conservative enlargement (39.43% and 32.41%). This distinct pattern can likely be attributed to the interaction between the instrument's nominal taper and its specific flute design, a characteristic feature of the Logic system where cross-section varies with taper. These results, highlighting the pivotal role of instrument taper on foraminal enlargement, find support in the recent work [15]. Their study compared several systems, including ProTaper Universal (tip size 25) and TruNatomy (tip size 26), which share similar final tip diameters to the instruments used in our study but feature distinctly different tapers (.08 and .04, respectively). In their findings, the system with the larger taper (ProTaper Universal) resulted in significantly greater foraminal transportation and less preservation of circularity compared to the system with the smaller taper (TruNatomy). While factors such as alloy and cross-sectional design undoubtedly contribute to the overall performance, the comparison between these two instruments underscores that taper is a variable influencing apical morphology, even when final tip sizes are closely matched. This corroborates our observation that within the same file system, taper variation alone significantly influences the extent of apical preparation.

The Logic 25/.03 and 25/.05 instruments, which feature a double-helix ("S") cross-section, resulted in the most conservative foraminal enlargement. This specific design is engineered to enhance flexibility and improve debris evacuation, thereby reducing torsional stress. A potential consequence of this geometry, however, is a reduction in radial contact with the dentinal walls compared to the more engaging square (25/.01) or triple-helix (25/.04) cross-section [16]. This characteristic may explain the smaller enlargement observed with these tapers, suggesting that while they provide safe preparation, they may be more conservative in terms of tissue removal at the apical foramen.

The Logic 25/.04 instrument, featuring a triple-helix cross-section, produced an intermediate level of foraminal enlargement (68.53%). This geometry is recognized for its balanced design, offering three cutting edges for efficient dentin removal while simultaneously providing adequate space for debris coronally [17]. This balance between cutting efficiency and debris removal capacity likely accounts for its intermediary performance, positioning its effect on apical dentin removal between the more aggressive square cross-section and the more conservative double-helix design.

The tip areas of the instruments were measured using a stereomicroscope, and no significant differences were found among them. It is believed that the quadrangular cross-section of the 25/.01 instrument promotes greater contact with the canal walls in the apical foramen region and, consequently, greater apical foramen enlargement.

Apical foramen deformation is a known iatrogenic complication of curved canal preparation that can compromise apical sealing and treatment prognosis [7; 8]. In the present study, the absence of significant differences in foraminal shape alteration across all Logic instrument groups indicates that their overall design and thermal treatment can respect of original canal anatomy [18]. This finding suggests that contemporary file systems, through advanced metallurgy and design, can achieve effective debridement while minimizing procedural errors, even in the challenging apical third of curved canals [19].

This study elucidates the significant influence of instrument taper on apical foraminal enlargement in the curved mesial canals of mandibular molars. The findings demonstrate that while all tested tapers increased the foraminal area, the magnitude of enlargement was taper-dependent. This variable dentin removal was achieved without inducing significant alterations to the foraminal morphology. Consequently, the selection of a final instrument taper can be strategically tailored to specific clinical objectives, allowing clinicians to optimize apical patency and debridement with the lowest risk of procedural errors [20].

Our study has inherent limitations that must be acknowledged. As an in vitro investigation utilizing extracted teeth, it cannot fully replicate the in vivo environment, including the biomechanical support of the periodontal ligament. Furthermore, while stereomicroscopy provided two-dimensional data on foraminal area, a micro-computed tomography (micro-CT) analysis would offer a superior, three-dimensional assessment of uninstrumented areas and potential canal transportation [1; 21]. Future studies should build upon these findings by employing micro-computed tomography to conduct comparative analyses of file systems with varying designs, thermal treatments, and irrigation protocols. Furthermore, as the present study utilized a final apical preparation size of 25, subsequent research should evaluate the impact of larger master apical file sizes (e.g., 35 and 40) on foraminal morphology.

CONCLUSION

Within the parameters and limitations of this study, all tested tapers of the Logic file system effectively enlarged the apical foramen without inducing significant alterations to its circular morphology. The final taper, however, is a determining factor for the extent of enlargement, with the 25/.03 and 25/.05 instruments providing the most conservative preparation.

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