# Micro-Computed Tomography Evaluation of Three-Dimensional Analysis of First Mandibular and Second Maxillary Premolars Apical Constrictions

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**Abstract**

Apical constriction is the narrowest diameter of the root canal system that commonly is used as a reference point by clinicians as apical termination in endodontic treatment. We investigated the three-dimensional (3D) analysis of shape, size, and location of apical constriction in first mandibular and second maxillary premolars.

Total 66 samples of extracted premolar teeth (due to orthodontic treatment) were selected. Selection criteria were complete root development, no restoration, no signs of root fracture or resorption, no radicular or coronal caries, and no endodontic treatment. After placement for 1 h in 3% hydrogen peroxide, and then storage in 70% alcohol, each tooth was scanned using a Bruker Skyscan 1173 micro-CT. The teeth were made transparent to reveal the root canal system morphology in 3D. The shape, size, and location of apical constriction were analyzed.

Most apical constriction shapes in first mandibular and second maxillary premolars were convergent and branched constrictions, with most locations tending to be apical. Mean distance between apical constriction and apical foramen was 0.619 and 0.647 mm in first mandibular and second maxillary premolars, respectively. The variation in shape, size, and location of apical constriction should be considered by dentists performing endodontic treatment.

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## Introduction

Triad endodontics is the principle of endodontic treatment consisting of biomechanical preparation, microbial control, and complete obturation of the root canal system.[1] Endodontic treatment begins with access preparation into the root canal through the working length from the orifice to the apical foramen. Root canal anatomy of the apical area consists of apical constriction, cementodentinal junction, and apical foramen.[2,3] This anatomy is considered apical termination of endodontic treatment, also known as “apical stop”.[2] Understanding the complexity of root canal morphology is important for determining the apical stop in endodontic treatment.[4]

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Ricucci and Langeland[5] showed that instrumentation and obturation to the apical constriction provided the best prognosis. Apical constriction has been defined as the narrowest diameter of the root canal system that is commonly used as a reference point by clinicians as the apical termination in endodontic treatment. Dummer et al. first classified the apical constriction shape into four types: (1) single (the canal widened apically and coronally to the narrowest zone), (2) taper (constantly narrowed toward the apex with the narrowest part coincided within 0.1 mm from apical foramen), (3) multi (a number of constrictions were present and (4) parallel (when the narrowest part of the canal extended for a long distance [>2.5 mm] and widened only at 0.1 mm from the apical foramen).[6,7]

The apical constriction size in this study was defined as the distance between apical constriction and the apical foramen. Dummer et al.[7] reported a mean apical constriction size of 0.55 and 0.53 mm in the first mandibular and second maxillary premolars, respectively. Kuttler[8] also suggested that endodontic treatment should be terminated at 0.5 mm from the apical foramen, as the nearest point to apical constriction. Apical constriction location in this study is based on its curvature position to the apex, following location of the apical foramen. Naseri et al. using cone beam computed tomography (CBCT), suggested that the apical foramen usually has a lateral deviation.[8] Milano et al. also suggested that only 12.6% of apical foramens at the apex center, while 61.7% of all apical foramens have deviation to distal and 12.2% to mesial locations.[9]

The morphology of the root canal system can be evaluated using several methods, such as radiographic and cross-sectional methods. The radiographic method only provides two-dimensional (2D) analysis that cannot accurately reveal the morphologic complexity of the root canal system, while the cross-sectional method is invasive. Recently, the micro-CT method was used to study morphologic evaluation of the root canal system because it offers a three-dimensional (3D) analysis of the root canal with high resolution and is noninvasive, providing substantial information about minor structures, such as apical constriction.[10,11] We investigated the 3D analysis of shape, size, and location of apical constriction in first mandibular and second maxillary premolars using the micro-CT method.

## Materials and methods

### Tooth Selection

Of 62 first mandibular and 50 second maxillary premolar teeth extracted due to orthodontic treatment between June and August 2017, 37 and 29, respectively, were selected for study. Selection criteria were complete root development, no restoration, no signs of root fracture or resorption, no radicular or coronal caries, and no endodontic treatment. The teeth were cleaned of any attached hard or soft tissues and calculus, placed in 3% hydrogen peroxide for 1 h, and stored in 70% alcohol.

### Micro-CT Morphologic Analysis

The teeth were scanned using a Bruker (Billeria, MA, USA) Skyscan 1173 micro-CT at settings of 130 kV and 60 μA, resulting in 800–1000 slices per tooth at an isotropic resolution of 50 μm. Specific software, such as CT Vox (Bruker), was used to differentiate tooth structures contrast to reveal the apical constriction location. The apical constriction shape was analyzed using CT An and CT Vol software, and the apical constriction size was analyzed using Fiji-ImageJ software 2012.

## Results

In this study, apical constriction shape was classified into seven types: (1) type A – single well-shaped constriction, (2) type B – irregular or multi constriction, (3) type C – convergent constriction, (4) type D – parallel constriction, (5) type E – divergent constriction, (6) type F – branched constriction, and (7) type G – apical delta (Fig. 1). Most apical constriction shapes in the first mandibular and second maxillary premolars were convergent and branched constrictions (Table 1).

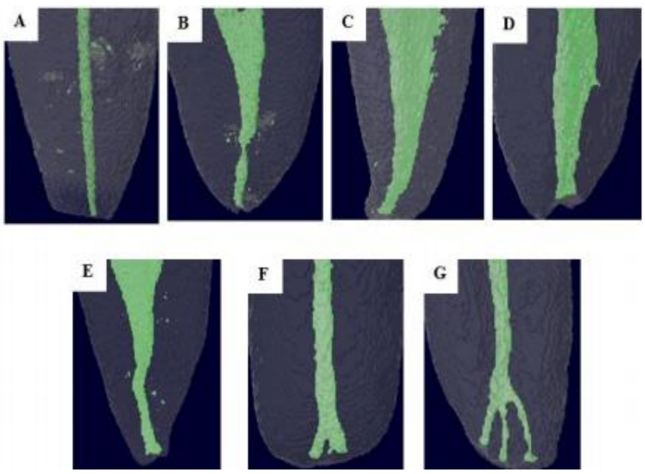


**Figure 1.** Apical constriction shape based on 3D visualization on CT Vol software: (A) single well-shaped, (B) irregular or multi constriction, (C) convergent, (D) parallel, (E) divergent, (F) branched, (G) apical delta.

| Apical Constriction Shape | Premolar Teeth | | Total n (%) |
|---|---|---|---|
| | First Mandibular n (%) | Second Maxillary n (%) | |
| Single well-shaped | 4 (10.80) | 2 (6.90) | 6 (9.10) |
| Irregular or multi constriction | 4 (10.80) | 1 (3.40) | 5 (7.60) |
| Convergent | 13 (35.10) | 5 (17.20) | 18 (27.30) |
| Parallel | 2 (5.40) | 1 (3.40) | 3 (4.50) |
| Divergent | 2 (5.40) | 5 (17.20) | 7 (10.6) |
| Branched | 7 (18.90) | 10 (34.50) | 17 (25.8) |
| Apical delta | 5 (13.50) | 5 (17.20) | 10 (15.2) |
| Total | 37 (100) | 29 (100) | 66 (100) |

**Table 1.** Distribution Table of Apical Constriction Shape in First Mandibular and Second Maxillary Premolars.

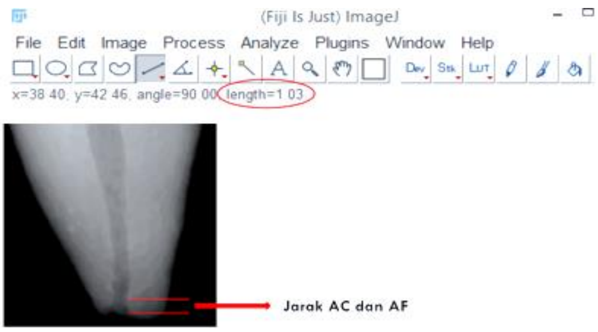


**Figure 2.** Measurement of apical constriction size.

| Apical Constriction Location | Premolar Teeth | | Total |
|---|---|---|---|
| | First Mandibular *n* (%) | Second Maxillary *n* (%) | *n* (%) |
| **More apical** | 19 (51.40) | 13 (44.80) | 32 (48.50) |
| **More mesial** | 5 (13.50) | 5 (17.20) | 10 (15.20) |
| **More distal** | 7 (18.90) | 2 (6.90) | 9 (13.60) |
| **Mesial and distal** | 3 (8.10) | 7 (24.10) | 10 (15.20) |
| **Apical, mesial, and distal** | 3 (8.10) | 2 (6.90) | 5 (7.60) |
| **Total** | 37 (100) | 29 (100) | 66 (100) |

**Table 2.** Distribution of Apical Constriction Location in First Mandibular and Second Maxillary Premolars.

The apical constriction size was defined as the distance between apical constriction and the apical foramen. Mean apical constriction size was 0.619 and 0.647 mm in the first mandibular and second maxillary premolars, respectively (Fig. 2).

In this study, the apical constriction was located by categorizing it based on its curvature. Most apical constrictions tend to be located apically (Fig. 3, Table 2).

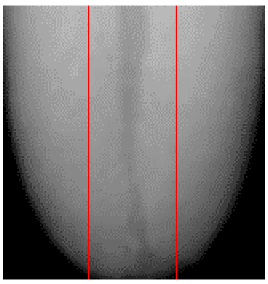

**Figure 3.** Determining the location of apical constriction.

## Discussion

The study samples were collected according to previous research by Dummer et al.[7] without considering patient age, using selection criteria, and they were taken from a particular population over a period of time. We investigated the 3D analysis of shape, size, and location of apical constriction in first mandibular and second maxillary premolars using the micro-CT method.

Apical constriction shape was first described by Dummer et al.[7] in 1984 and classified into four types: (1) single, (2) taper, (3) multi, and (4) parallel constriction. This classification was later developed by Citterio et al.[12] in 2014 because the Dummer et al.[7] classification could not be applied to a complex apical constriction and could not represent apical constriction shape in 3D. Citterio et al.[12] classified apical constriction into six types: (1) type A – single constriction, (2) type B – multi constriction, (3) type C – taper constriction, (4) type D – flaring root canal, (5) type E – parallel constriction, and (6) type F – apical delta.[12] Our study adopted the early classification according to Dummer et al.[7] as modified by Citterio et al.[12] However, after complete identification thoroughly in the longitudinal direction, both classifications must be converted into a new variation based on the sample findings (Fig. 1).

The results in first mandibular premolars showed that convergent constriction was found most often (35.14%), followed by branched constriction (18.92%), with parallel or divergent constriction found least often (5.41%). Whereas in second maxillary premolars, branched constriction occurred most often (34.38%), followed by convergent or divergent constriction or apical delta (17.24%), and finally by irregular or parallel constriction (3.45%; Table 1). These results correspond to those of previous studies suggesting that first mandibular and second maxillary premolar have a complex anatomic variation at the 1/3 cervical, 1/3 middle, and 1/3 apical sections of the root canal system, including the apical constriction shape.

In contrast, Citterio et al.[12] also used micro-CT and reported that the most common apical constriction shapes were flaring root canal (25%), single constriction (21.2%), parallel constriction (21.1%), taper constriction (19.7%), apical delta (10.5%), and branched constriction (2.6%). The differences from our results are due to differences in classification of the apical constriction shape, number of sample size, and different types of sample investigated. Citterio et al.[12] only studied 15 samples of incisive, premolar, and molar teeth.

Our results were also not in agreement with those of Dummer et al. due to cutting the root apex longitudinally using a diamond disc.[7] The slice then was soaked with blue food dye and the coloring results were viewed in 2D using a microscope with ×20 magnification. Dummer et al.[7] reported that 46% of apical constrictions are single, 30% taper, 19% branched, and 5% parallel constrictions. The difference in this study is due to the different methods of analysis, where in their study, apical constriction shape was analyzed in 2D, so that they were less able to describe the complexity of apical constriction shape.[13]

We analyzed apical constriction size using Fiji ImageJ software because the process is simple and the result is more valid because the measurement result is viewed directly on the main menu of the software. The image measured is taken from the 3D visualization that has been processed in the CT Vox software, so that anatomy of the apical constriction is clearly visible. To make the measurement, first two guidance points located on the apical constriction are created as the area with the smallest diameter and the apical foramen seen as the area with the largest diameter. Then, the measurements can be made directly by drawing a line connecting the two points, and the results will be viewed on the main menu of the Fiji ImageJ software (Fig. 2).

Previously, Piasecki et al.[14] also measured the distance between apical constriction and apical foramen using a digital caliper. The measurement was made by inserting the K-file #15 into the root canal connected with a digital caliper with an accuracy of 0.01 mm. The K-file tip is positioned at the reference point at the root tip and the digital caliper is set to 0. The K-file then is raised to the apical foramen position and the measurement recorded, representing the distance between the apical foramen and apex. Apical constriction then is determined by reducing 0.5 mm from the measurement results.[14]

In this study, mean distance between the apical constriction and apical foramen was 0.619 and 0.647 mm in first mandibular and second maxillary premolars, respectively. Similar results, when compared to our study, were obtained by Kuttler,[15] who reported the distance between apical constriction and apical foramen to range from 0.524–0.659 mm; however, this study was performed on all types of teeth. Piasecki et al.[14] also reported a mean distance between apical constriction and apical foramen in mandibular premolars of 0.59 (range, 0.12–2.25) mm, but these measurements were performed using a digital caliper. Citterio et al.[12] also reported a mean distance of 0.72 ± 0.35 mm, but their study was performed on incisive, premolar, and molar teeth.

In first mandibular premolars, since the data were normally distributed, a one-sample t-test was used to check mean apical constriction size and compared to a single reference value of 0.55 mm set by Dummer et al.[7] There was a significant difference between mean apical constriction size in first mandibular premolars with this single reference value (significance value, 0.047; $P < 0.05$). In second maxillary premolars, since the data were abnormally distributed, a one-sample Wilcoxon test was used to check mean apical constriction size and compared to a single reference value of 0.53 set by Dummer et al.[7] The difference between mean apical constriction size in second maxillary premolars with this single reference value was significant (significance value, 0.000; $P < 0.05$). Therefore, the research hypothesis concerning the difference in apical constriction size in first mandibular and second maxillary premolars is accepted.

In this study, comparisons were performed with a single reference value according to Dummer et al.[7] because to our knowledge only this study has ever measured the distance between apical constriction to the apex and between the apical foramen to the apex in premolar teeth. In this study, the reference value was obtained from the difference in apical constriction distance to the apex and apical foramen to the apex; thus, obtaining apical constriction distance to the apical foramen. According to Dummer et al.[7] the distance between apical constriction and apical foramen is 0.53 and 0.55 mm in maxillary and mandibular premolars, respectively. Measurement in their study was done using a dissecting microscope with ×20 magnification, while we used micro-CT. Both studies similarly used a 1/3 apical tooth specimen cut at 5 mm from the apex.

Apical constriction location was analyzed by categorizing apical constriction based on its curvature, which was classified as more apical; more mesial; more distal; mesial and distal; and apical, mesial, and distal according to the 3D visualization results seen in the CT Vox software (Fig. 3). Apical constriction curvature in first mandibular and second maxillary premolars demonstrated the greatest distribution of apical constriction curvature that was located more apically. The sample distributions are shown in Table 2.

Our results are not in agreement with those of Naseri et al.[8] in the Iranian population using the CBCT method. They reported that the apical foramens usually have a lateral deviation. Deviation of apical foramen also will affect position of the apical constriction. The difference from our results are due to the different types of teeth investigated, since Naseri et al.[8] used maxillary molar teeth.[8] Milano et al. (in vitro studies) suggest that only 12.6% of root canals have apical foramens at the apex center. The apical foramen has the largest deviation to distal (61.7%) and mesial (12.2%). Tamse et al. also reported that the apical foramen located at the apex center is found only in 10%–15% of cases. The difference may be due to the different research methods used by Milano et al., who used a conventional radiographic method that only provided 2D root canal anatomy. In our study, using micro-CT displayed the complexity of root canal morphology, a 3D high resolution technique, and detailed imaging of tooth structure especially at the apical area.

The limitation of our study is the short period during which samples were collected, such that the number of samples was minimal. Our study also did not include age criteria, which may affect the distance between apical constriction and apical foramen where in older patients, apical constriction will be further away from the apical foramen due to a cementum deposit. In addition, our study was performed on a small population with a minimal sample types that could not illustrate the variation in a wider population.

## Conclusions

Most apical constriction shapes in first mandibular and second maxillary premolars were convergent and branched constrictions. Mean apical constriction size was higher than the single references value of Dummer et al.[7] Most apical constrictions locations tend to be apical.

## Acknowledgement

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## Declaration of Interest

Authors declare no conflict of interest.

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