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## **Accuracy of Cone-Beam Computed Tomography (CBCT) Systems for the Diagnosis of Mesio Buccal Canal Anatomy of Maxillary Molars**

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### **ABSTRACT**

**Introduction:** Maxillary molars have been well documented to have a high incidence of a second mesiobuccal canal (MB2). The identification of MB2 and clinical treatment of maxillary molar canal anatomy has been enhanced by the technology provided by cone-beam computed tomography (CBCT) in endodontics. The aim of this study was to evaluate the accuracy of five CBCT systems for the anatomical analysis of maxillary molars compared to the standard of micro-computed tomographic (micro-CT) imaging.

**Methods:** Fifty-two extracted maxillary molars were mounted, using wax to simulate periodontal ligament and periapical bone loss, in twenty-six maxilla jig casts. The casts were constructed of plaster and ground rice and layered with wax to mimic boney trabeculation and noise created by soft tissue. Each of the 52 mounted molars were scanned in the 3D Accuitomo 80, Veraviewepocs 3D R100, iCAT FLX, Carestream CS9300, ProMax 3D Max systems, and micro-CT (the reference standard). The scans were reviewed by two board certified endodontists and one oral maxillofacial radiologist, using the corresponding system's viewing software for the presence of MB2, to determine whether the mesiobuccal canals joined (MB2 with MB1), and for the number of apical exits that could be identified. The gold standard (micro-CT) was compared with each machine using McNemar's tests for proportions, and the number of apical exits were compared using Wilcoxon Signed Rank test. Sensitivity and specificity were calculated for each machine. Inter-rater and the intra-rater agreement were calculated using Fleiss' Kappas. Statistical analyses were performed using SAS version 9.4 (Statistical Analysis Software, Cary, NC).

**Results:** No significant difference was found between the five CBCT systems in MB2 identification as compared to the reference standard of micro-CT (McNemar,  $p < 0.05$ ). Micro-CT detected a significantly greater number of apical exits than any of the five systems (Wilcoxon Signed Rank test,  $p < .0001$ ). Accuitomo identified a significantly greater number of apical exits compared to iCAT, Carestream CS9300, and ProMax. Veraviewepocs had a significantly greater number of apical exits reported compared to iCAT and ProMax. There was no significant difference in apical exit identification between Veraviewepocs and Accuitomo. A significant difference was found between micro-CT and the Accuitomo and Veraviewepocs in determining if the mesiobuccal canals joined.

**Conclusion:** While Micro-CT was significantly better for identifying apical anatomy than all CBCT systems, the CBCT systems studied were found to be highly accurate in MB2 identification. There was no significant difference between micro-CT and the iCAT FLX, Carestream CS9300, and Planmeca ProMax3D Max for determining if MB2 joined MB1. There was a significant difference between the gold standard of micro-CT and the 3D Accuitomo 80 and Veraviewepocs 3D R100. Among CBCT machines studied, 3D Accuitomo 80 better

identified the number of apical exits than iCAT FLX, Carestream CS9300 and Planmeca ProMax 3D Max, but was not significantly better than Veraviewepocs 3D R100.

## **INTRODUCTION**

The incidence of a second mesiobuccal canal (MB2) in maxillary molars is well documented. Studies have used multiple methods such as clinical access, sectioning extracted teeth, ink, radiographs, cone-beam computed tomography (CBCT) imaging, and micro-computed tomographic (micro-CT) imaging to determine the incidence of MB2. Research suggests the incidence of MB2 in first molars is 51.5-96.1% and 29-93.7% in second molars (1-7). Locating and treating all canals is vital to the success of root canal therapy (RCT). Endodontically treated teeth with missed canals were found to have greater odds of periapical lesions and maxillary first molars have been found to have the highest prevalence of missed canals at 59.5%, followed by maxillary second molars at 40% (8).

Searching for the presence and location of MB2 can complicate endodontic treatment of maxillary molars. As techniques and technologies improve, the clinician is better able to locate and treat MB2. A clinical investigation of maxillary molar canal morphology over an eight year period found that after the dental operating microscope (DOM) was used regularly along with improved instruments for troughing, the likelihood of discovery and instrumenting MB2 increased and, in the final year of the data collection, the incidence of MB2 in treated teeth was 93.0% for first molars and 60.4% in second molars, an increased incidence of 9% and 9.7%, respectively. (9). An in-vivo comparison of the DOM, loupes, and no magnification found that the use of magnification significantly increased the likelihood of finding MB2, with 57.4% MB2 incidence using the microscope compared to 18.2% using no magnification (10). The use of CBCT has been shown to enhance the detection of MB2 in maxillary molars by up to 11.7% (11). Further, CBCT has been shown to have a high level of sensitivity (96.6%) and specificity (85.1%) (12), greater than radiography for detecting MB2 (13). According to the American Association of Endodontists (AAE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR) Joint Position Statement: Use of Cone Beam Computed Tomography in Endodontics 2015 Update, a limited field of view (FOV) CBCT should be considered preoperatively when complex anatomy is anticipated and for mid-treatment to aid in the identification of calcified canals (14).

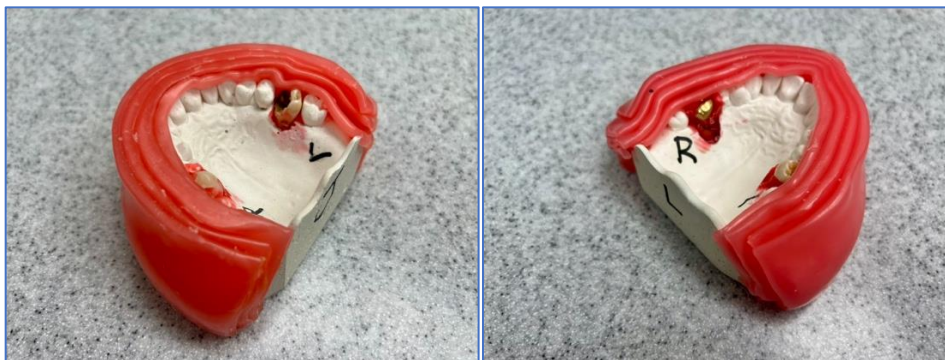
A review of literature identified only one study comparing CBCT systems for the accuracy of identification of MB2 in maxillary first molars (15). The systems evaluated were the i-CAT Classic (Imaging Sciences International, Hatfield, PA), i-CAT Next Generation (Imaging Sciences International, Hatfield, PA), and the PreXion 3D (PreXion, San Mateo, CA), in which the PreXion 3D was found to be the most effective for the diagnosis of mesial buccal root anatomy (15).

Evaluating the accuracy of CBCT systems using anatomical analysis of maxillary molars may aid in making an informed decision regarding the purchase of a CBCT system specific for endodontic practice. The aim of this study was to determine if there was a significant difference between the 3D Accuitomo 80 (J. Morita, Irvine, CA), Veraviewepocs 3D R100 (J. Morita, Irvine, CA), iCAT FLX (Kavo, Hatfield, PA), CS9300 (Carestream, Atlanta, GA), or ProMax

3D Max (Planmeca, Hoffman Estates, IL) systems based on: 1.) the identification of MB2 in maxillary molars; 2.) identifying if MB2 joins the first mesiobuccal canal (MB1); and 3.) their ability to differentiate the number of apical exits using micro-CT as the standard. The null hypotheses: 1.) There is no significant difference in the accuracy of identification of MB2 in maxillary molars between the five CBCT systems and micro-CT; 2.) There is no significant difference in the accuracy of the five CBCT systems and micro-CT in determining if MB2 joins MB1; and 3.) There is no significant difference between the five CBCT machines and micro-CT in the identification of the number of apical exits. Alternative hypothesis: There is a significant difference between the five CBCT systems and micro-CT in the accuracy achieved in identifying MB2 anatomy and for determining apical anatomy in maxillary molars.

## MATERIALS AND METHODS

The 59<sup>th</sup> Medical Wing Institutional Review Board approved this study. Fifty-two extracted maxillary first, second, and third molars; twenty-six left and twenty-six right, were collected without identifying information and stored in 10% formalin solution. Teeth were collected without any patient information. To be included in the sample, teeth had to have a complete mesial buccal root with fully formed apex. Teeth with coronal restorations, caries, and fused palatal and distal buccal roots were accepted. Previously endodontically treated teeth and teeth with mesiobuccal roots fused with other roots were not included. Maxillary jigs were constructed of plaster mixed with ground rice to mimic trabeculated alveolar bone, followed by layered utility wax of 13 to 17 mm on the plaster cast to simulate the gingiva and soft tissue of the cheek to reproduce appropriate radiographic noise (15-18). One left and one right molar were mounted into the appropriate anatomical area of a first molar in the custom jig to simulate the maxilla. Each test tooth was mounted in the maxillary cast jig in utility wax to model periodontal ligament (PDL) space and periapical bone loss (Figures 1 and 2). The teeth were mounted in the jigs such that the cemento-enamel junction was parallel to the scanning platform for each CBCT system (Figure 3). All teeth were scanned facing the same direction using a platform on each CBCT system.



*Figure 1 and 2: Left and right maxillary molars mounted in jig cast constructed of plaster mixed with ground rice and wax to simulate bone trabeculation and soft tissue. Sample “RL” is seen in Figure 2 with a gold crown.*



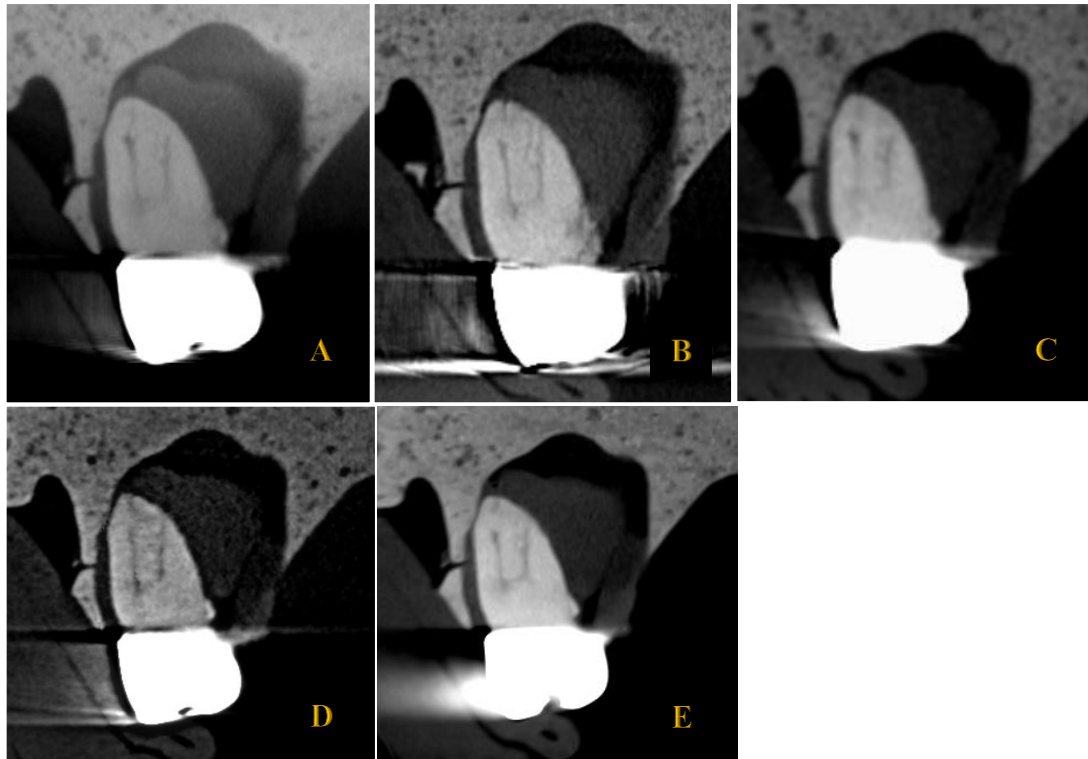
Figure 3: Samples on platform for scanning on 3D Accuitomo 80.

The CBCT scans were acquired with high resolution while using each system's smallest FOV and voxel size settings (Table 1). CBCT images were evaluated using each system's 3D medical imaging processing software. Two board certified endodontists and one board certified oral maxillofacial radiologist reviewed the CBCT images in dim lighting with all samples from each CBCT system being viewed before moving to another system. Since each system's processing software was used for viewing the images, it was not possible to blind the reviewers to the different CBCT systems. Teeth were evaluated in random order, distinguished by the arbitrary identifier known only by the primary investigator. The mesiobuccal roots were viewed axially, coronally, and sagittally in the CBCT slices multiple times to allow the reviewers time to view the CBCT scan in its entirety. Brightness and contrast were adjusted by the primary investigator as requested by the reviewers.

Table 1: CBCT systems, viewing software, and scan parameters.

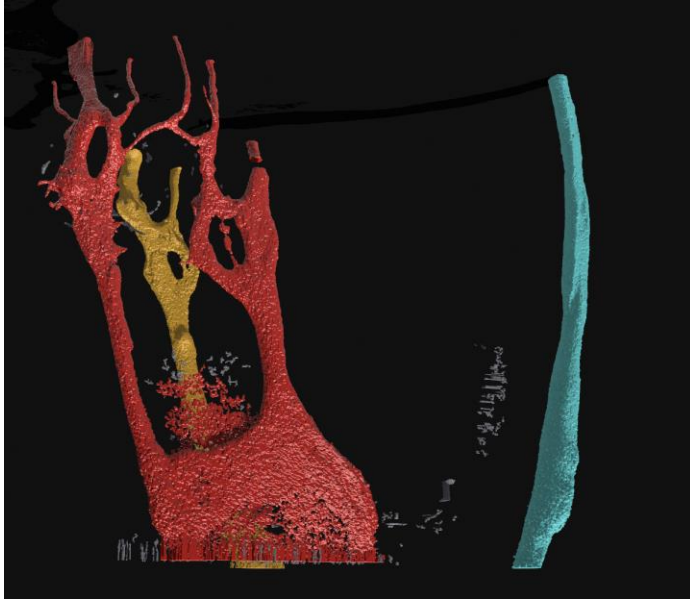
CBCT Model	Manufacturer	Viewing Software	FOV (mm)	Voxel (mm)	kVp	mA	Seconds
3D Accuitomo 80	J. Morita	One Volume Viewer	40 x 40	0.080	90	5	17.5
Veraviewepocs 3D R100	J. Morita	One Volume Viewer	40 x 40	0.125	90	8	9.4
iCAT FLX	Kavo	InVivoDentalViewer by Anatomage, Inc	80 x 80	0.120	120	5	26.9
CS9300	Carestream	CS 3D Imaging	50 x 50	0.090	84	5	19.96
ProMAX 3D Max	Planmeca	Planmeca Romexis Viewer	50 x 55	0.100	96	11	12

For each sample evaluated in each CBCT system, the three reviewers were asked the following: “Is MB2 visible at any level?” with the option to answer “Yes” or “No”, if MB2 was visible, then “Does MB2 join MB1?” was asked with the option to answer “Yes” or “No”, and finally, “What is the number of apical exits?” with possible numerical answers in the range of 1-8. One week later, the three reviewers re-evaluated 13 samples (25%) to determine intra-rater consistency and reliability.



*Figure 4: Coronal sections of sample “RL” for each CBCT system and viewing software. A. Scanned in 3D Accuitomo 80, viewed in One Volume Viewer; B. Scanned in Veraviewepocs 3D R100, viewed in One Volume Viewer; C. Scanned in iCAT FLX, viewed in InVivoDentalViewer by Anatomage, Inc.; D. Scanned in Carestream CS9300, viewed in CS 3D Imaging; E. Scanned in ProMax 3D Max, viewed in Planmeca Romexis Viewer.*

The 52 sample teeth were scanned using micro-CT (SkyScan 1172 Version 1.5 (build 28) A, Bruker, Billerica, MA) with the settings of 85kV, 118 mA, with a rotational step of 0.4°, a pixel size of 10.5  $\mu\text{m}$ , and aluminum filter (0.5 mm of thickness). The average scanning time was 55 minutes per sample. Images were reconstructed using the NRecon software (Version 2.0.0.5, Bruker, Billerica, MA). CTAn software (Version 1.20.3.0, Bruker, Billerica, MA) was used for analysis and processing of the images to create 3D models of the internal canal anatomy in STL file format. CTVol software (Version 2.3.2.0, Bruker, Billerica, MA) was used to visualize 3D models of the canal anatomy. These 3D models were used as the standard to identify the maxillary molar anatomy for the presence or absence of a second mesiobuccal canal, and when a second canal was present, to assess whether MB2 joined MB1, and to account for the number of apical exits.



*Figure 5: 3D model of micro-CT taken of "RL", a right maxillary molar sample, with the mesiobuccal root highlighted in red. MB2 is visible and there are 6 apical exits. Model created with color in Shapr3D (Shapr3D, Budapest, Hungary).*

## **Statistical Analysis**

Micro-CT results were compared with each of the five CBCT systems using McNemar's tests for the if MB2 was visible at any level, and, if MB2 was visible, did it anatomically join the other mesiobuccal canal. The number of apical exits visible in micro-CT and each CBCT system were compared using Wilcoxon Signed Rank test as the data was not normally distributed. Sensitivity and specificity of each CBCT system were calculated against the gold standard of micro-CT. Inter-rater and the intra-rater reliability and consistency was calculated using Fleiss' Kappa. Statistical analyses were performed using SAS version 9.4 (Statistical Analysis Software, Cary, NC).

## **RESULTS**

There was no significant difference between the five CBCT systems and micro-CT for identification of MB2 (McNemar's test,  $p < 0.05$ ). Therefore, the first null hypothesis is accepted.

A significant difference between micro-CT and both the 3D Accuitomo 80 and Veraviewepocs 3D R100 was observed for identifying if the second mesiobuccal canal joined the first canal (McNemar's test,  $p < 0.05$ ). As a result, the second null hypothesis is rejected because there is a difference in the determination of whether the two canals join.

Micro-CT detected a significantly greater number of apical exits than any of the five CBCT systems (Wilcoxon Signed Rank test,  $p < .0001$ ) (Table 2). Pair-wise comparisons among the five CBCT systems for the number of apical exits showed that the 3D Accuitomo 80 system

identified a significantly greater number of apical exits than iCAT FLX, Carestream CS9300 and Planmeca ProMax 3D Max, but was not better than Veraviewepocs 3D R100 (Table 3). Furthermore, the Veraviewepocs 3D R100 showed a significantly greater number of apical exits reported compared to the iCAT FLX and the Planmeca ProMax 3D. Consequently, the third null hypothesis is rejected because there is a difference between micro-CT and the CBCT systems. The alternative hypothesis is accepted because there is a significant difference among CBCT machines and micro-CT accuracy in identifying MB2 anatomy and for determining apical anatomy in maxillary molars.

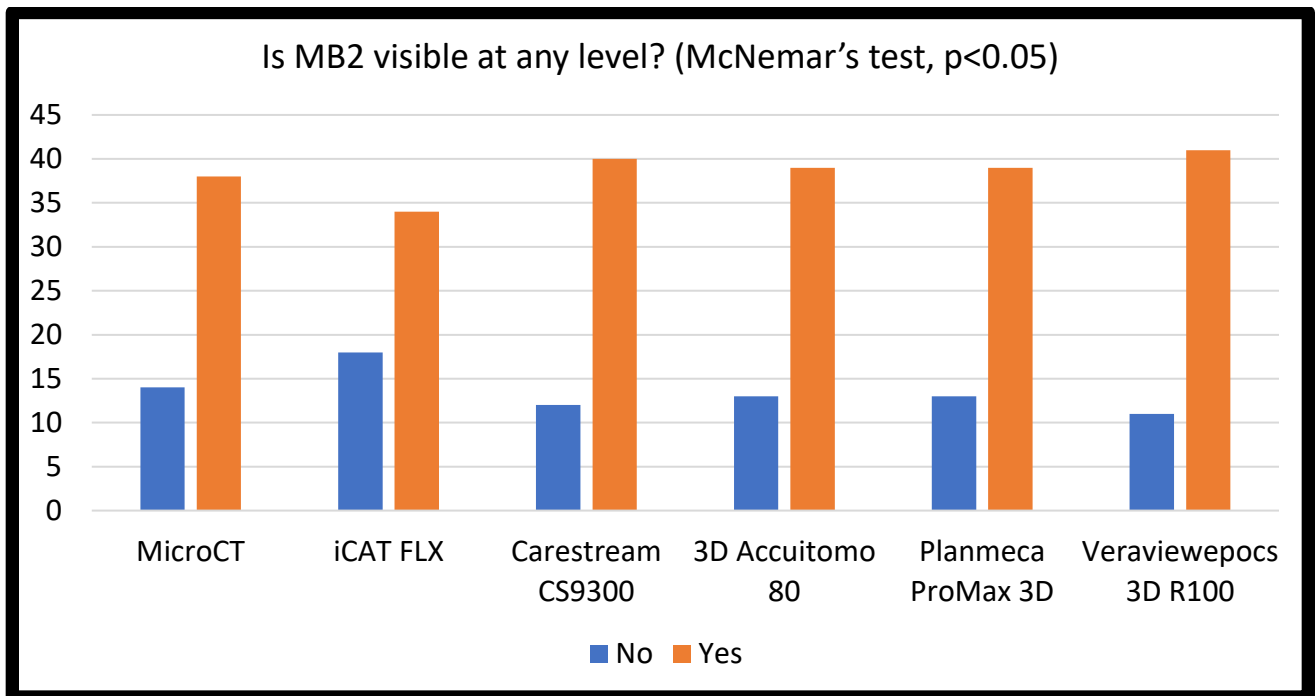


Figure 6: Micro-CT results were compared with each of the five CBCT systems using McNemar's test for if MB2 was visible at any level. No significant difference was found between the five CBCT systems and micro-CT in MB2 identification.

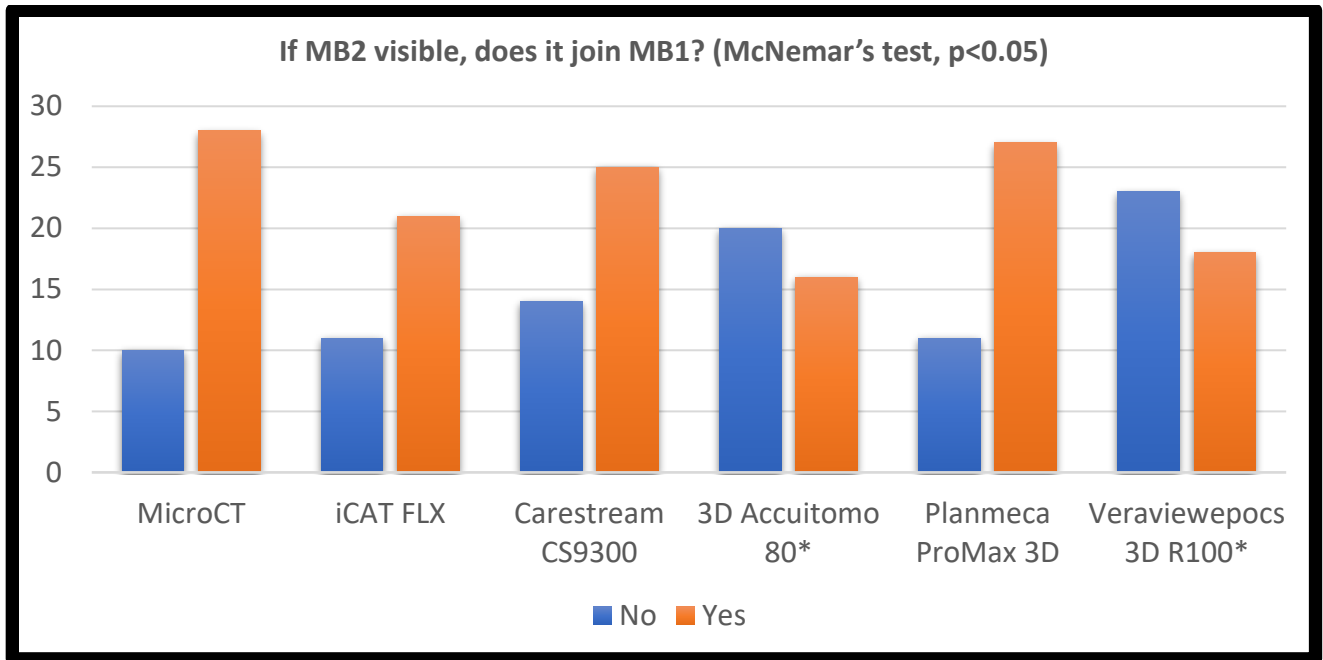


Figure 7: McNemar's test was used to determine the significance for when MB2 was visible, did it join MB1? (\*denotes a significant difference).

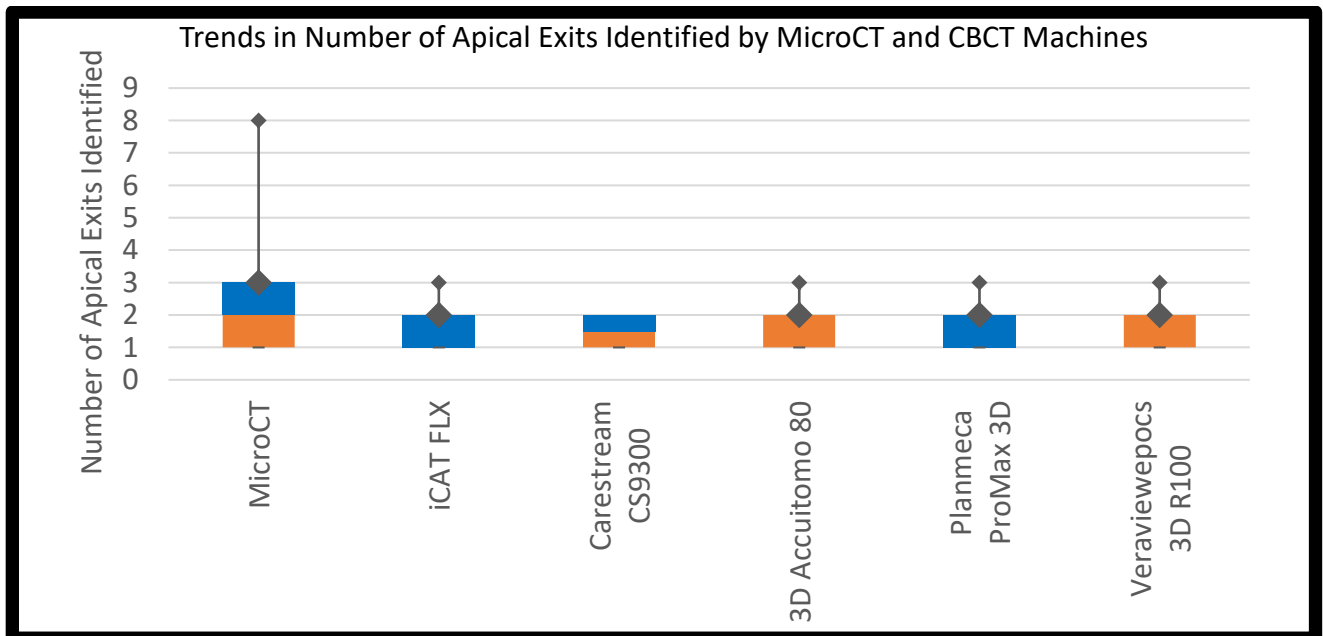


Figure 8: The number of apical exits visible in micro-CT and each CBCT system were compared using Wilcoxon Signed Rank test as the data was not normally distributed. Micro-CT detected a significantly greater number of apical exits than any of the five CBCT systems ( $p < .0001$ ). The maximum and minimum number of apical exits reported for each system along with the median and lower and upper quartiles are displayed above.

Table 2: Wilcox Signed Rank Statistic comparing number of apical exits to micro-CT. Note the larger the statistic, the greater the difference from micro-CT value.

**Number of Apical Exits Compared to Micro-CT**

CBCT System	Wilcoxon Signed Rank Statistic	p
<b>3D Accuitomo 80</b>	137	<.0001
<b>Veraviewepocs 3D R100</b>	150	<.0001
<b>iCAT FLX</b>	203	<.0001
<b>Carestream CS9300</b>	173	<.0001
<b>Planmeca ProMax 3D</b>	189	<.0001

Table 3: Pairwise comparisons of CBCT Systems for number of apical exits reported. The Accuitomo had significantly higher numbers of apical exits reported compared to the iCAT, Carestream, and ProMax. The Veraviewepocs had significantly higher numbers of apical exits noted compared to the iCAT and ProMax.

**Pair-wise Comparison among 5 machines in reporting the number of apical exits.**

p-value	iCAT FLX	Carestream CS 9300	3D Accuitomo 80	Planmeca ProMax 3D
<b>Carestream CS9300</b>	0.41			
<b>3D Accuitomo 80</b>	<b>0.0001</b>	<b>0.006</b>		
<b>Planmeca ProMax 3D</b>	0.74	0.57	<b>0.0008</b>	
<b>Veraviewepocs 3D R100</b>	<b>0.004</b>	0.05	0.80	<b>0.004</b>

Sensitivity of the 5 CBCT systems ranged from 62% to 97%, and specificity ranged from 57% to 93% (Table 4, Figures 9, 10). The Veraviewepoc had the highest value for sensitivity in visualizing MB2, meaning when MB2 was present it was correctly identified in 97.37% of the samples. The iCAT was the lowest sensitivity at 81.5%. However, for recognizing whether MB2 joined MB1, the Accuitomo and Veraviewepoc had the lowest sensitivity at 61.90% and 68.18%, respectively, but the greatest specificity, both at 93.33%. Therefore, the Accuitomo and Veraviewepoc identified 93.33% of the time when MB2 did not join MB1. This may be more clinically relevant to best treat the apical anatomy.

Table 4: Sensitivity and Specificity for the 5 CBCT systems in identifying MB2 and whether MB2 joins MB1.

	Is MB2 visible at any level?		Does MB2 join MB1?	
	Sensitivity	Specificity	Sensitivity	Specificity
<b>3D Accuitomo 80</b>	94.74%	78.57%	61.90%	93.33%
<b>Veraviewepocs 3D R100</b>	97.37%	71.43%	68.18%	93.33%
<b>iCAT FLX</b>	81.58%	78.57%	78.95%	66.67%
<b>Carestream CS9300</b>	94.74%	71.43%	81.82%	78.57%
<b>Planmeca ProMax 3D</b>	86.84%	57.14%	85.71%	66.67%

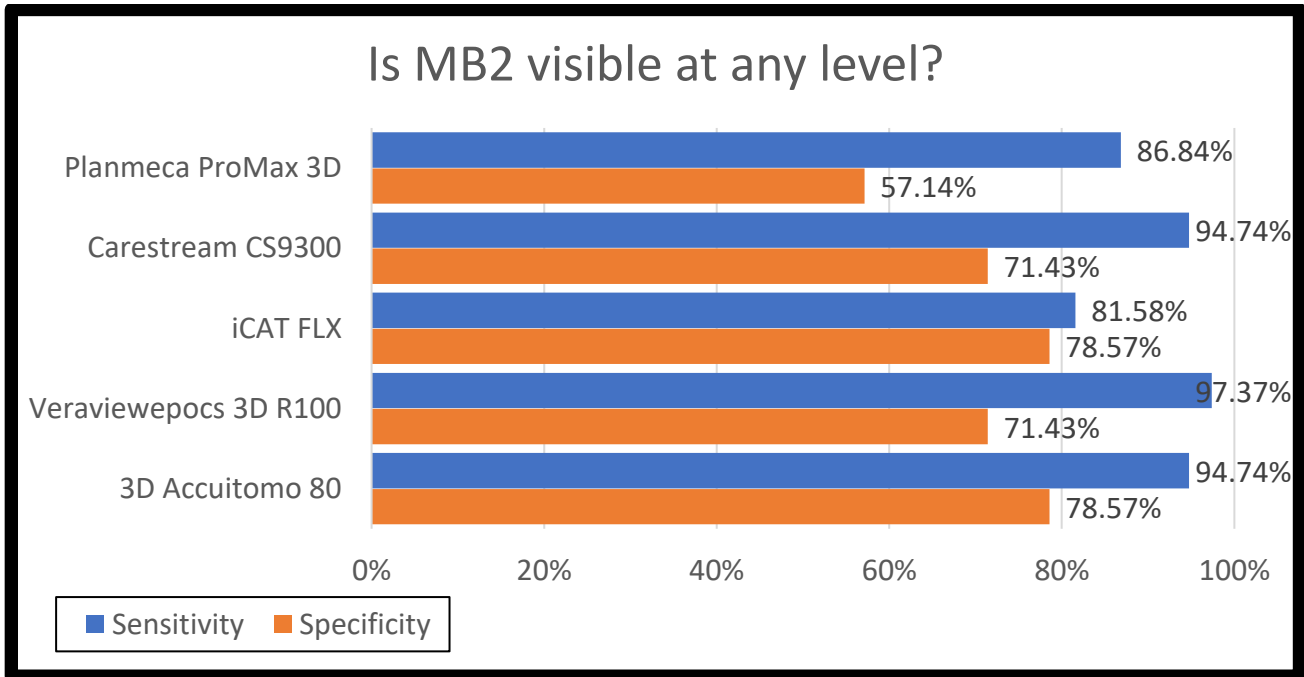
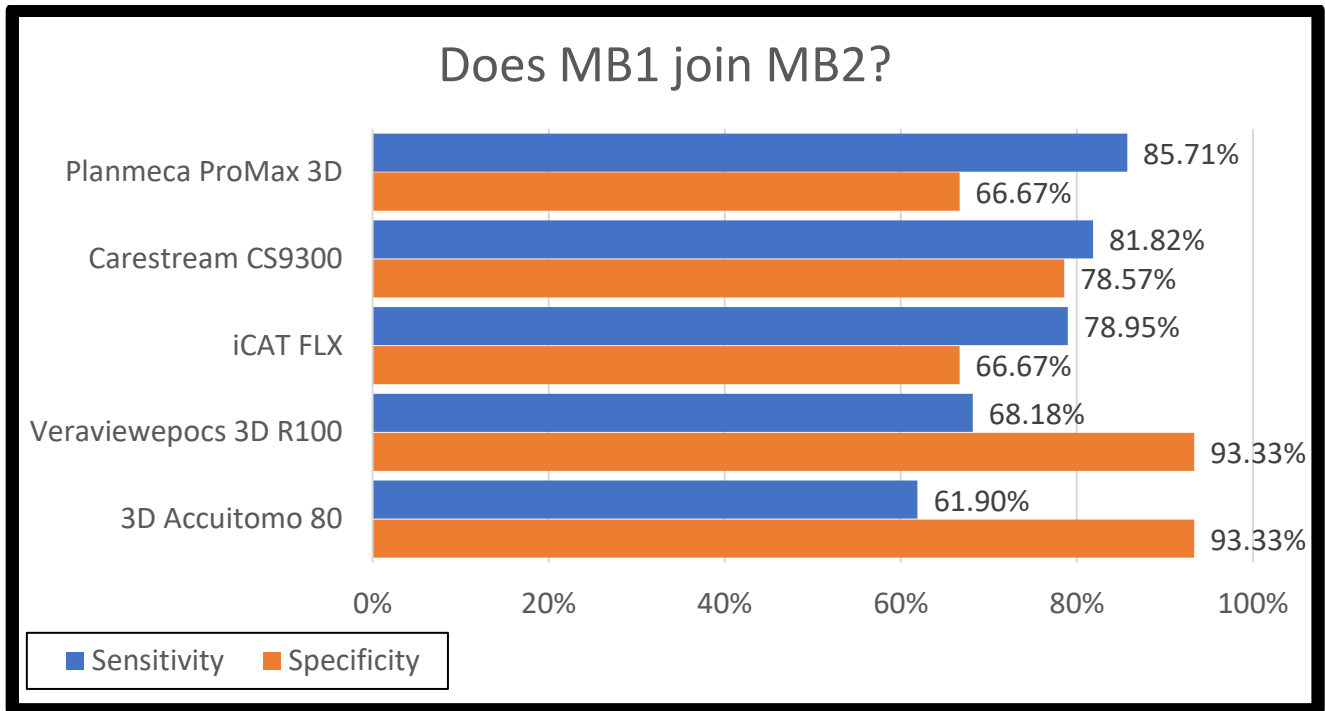


Figure 9: Sensitivity and specificity were calculated for each of the 5 CBCT Systems. The Veraviewepoc had the highest sensitivity in visualizing MB2, meaning when MB2 was present it was correctly identified in over 97 % of the samples. The iCAT had the lowest sensitivity. For specificity, or when MB2 was not present it was correctly identified, the Accuitomo and iCAT performed at the same level at greater than 78%.



*Figure 10: For recognizing whether MB2 joined MB1, the Accuitomo and Veraviewepoc had the lowest sensitivity, but the greatest specificity. Therefore, the Accuitomo and Veraviewepoc identified over 93% of the time when MB2 did not join MB1. This may be more clinically relevant to best treat the apical anatomy.*

Inter-rater and intra-rater reliability were examined using Fleiss' Kappa. Kappa values for inter-rater consistency ranged from 0.45 to 0.81, indicating moderate to an almost perfect level of agreement (19). Intra-rater consistency ranged from 0.41 to 1.00 indicating moderate to complete agreement between repeated assessments by individual reviewers (19).

## DISCUSSION

The selection and purchase of a CBCT system for a dental practice is a challenging decision. A provider must consider finances, space requirements, training of staff, and adaption of the technology into the practice, not to mention the quality of the imaging and the ability to identify the location of canals, resorptive lesions, perforations, and anatomical considerations for surgical planning. The ability to modify settings such as voxel size and FOV based on the anatomy, and the restorative and treatment history of each case, is also important. Multiple comparison studies of CBCT systems have been completed in-vivo and ex-vivo based on different radiographic findings like those described above (15, 20-29). This study aimed to evaluate CBCT systems based on the anatomy of maxillary molars given the clinical treatment challenges this tooth provides for dentists and endodontists.

More endodontists are incorporating CBCT imaging into their practices. A survey of AAE members published in 2017 found that 80.30% of respondents had access to a CBCT machine and 50.69% had one in their office (20). The majority of respondents reported utilizing a limited FOV (<5 cm diameter) (20) which is similar to the sizes included in this study. A second survey of AAE members published in 2019 found that 91.8% of respondents used CBCT in their practice with 86% having access in their office (21). The CBCT systems that the respondents reported using included 59.6% Carestream, 20.8% Morita and 5.7% Sirona, with the remaining reported as “other” (21). Based on the systems included in this evaluation, CBCTs have similar ability to visualize and identify MB2 as compared to micro-CT. All systems studied revealed the sensitivity of MB2 detection or ability to identify MB2 when it is present at 81.58% - 97.37%, similar to reported CBCT sensitivity of 96.6% (13).

The identification of MB2 with DOM has been reported to be significantly lower than with CBCT (30). Given MB2 incidence of up to 96.1% in first molars and up to 93.7% in second molars (1-7), the findings of this study would support the use of intraoperative CBCT imaging to improve endodontic treatment if MB2 is not initially located with the DOM alone and may even support CBCT imaging to verify apical anatomy even after MB2 is located. More research is needed to see how different apical MB root anatomy can effect treatment outcomes. When evaluating if MB2 joined MB1, the 3D Accuitomo 80 and Veraviewepocs 3D R100 were found to be significantly different from micro-CT. The same two systems had lower levels of sensitivity, but greater levels of specificity, and more frequently identified cases where MB2 did not join MB1. This would be clinically significant for the success of endodontic treatment to make sure all canals are appropriately treated. Maxillary molars with untreated mesiobuccal canals have been reported to be 3.1 times more likely to be associated with periapical pathology than those maxillary molars with no missed anatomy (8). The iCAT FLX, Carestream CS9300 and Planmeca ProMax 3D Max were not significantly different from microCT in identifying if MB2 joined MB1, however this may be less clinically relevant than identification of the presence of MB2 and the number of apical exits present for treatment success. The 3D Accuitomo 80 and Veraviewepocs 3D R100 identified a greater number of apical exits compared to the other CBCT systems evaluated. Being able to identify apical anatomy and appropriately treat improves the likelihood of treatment success.

A small voxel size (0.08 mm) has been shown to improve accuracy of the detection of MB2 in endodontically treated maxillary first molars, however the use of filters did not improve detection (31). The voxel size in our study ranged from 0.080 mm (3D Accuitomo 80) to 0.125 mm (Veraviewepocs 3D R100). This range did not appear to change results for identification of the presence of MB2, whether MB2 joined MB1, or for the number of apical exits as these two J. Morita systems performed similarly. While not specifically evaluated in this study, the ability of the viewing software to control image quality in areas such as noise, contrast resolution, artifact reduction, and reconstruction techniques must be considered. The 3D Accuitomo 80 and Veraviewepocs 3D R100 samples were both evaluated using the One Volume Viewer software. The viewing software and smaller FOV than the other system evaluated allowed better recognition of the number of apical exits while sacrificing accuracy of being able to tell if MB2 joined MB1. Only one study was identified comparing CBCT systems based on the accuracy of identification of MB2 in maxillary first molars (15). That study found the PreXion 3D to be the most effective CBCT system as compared to the i-CAT Classic and i-CAT Next Generation in

determining mesial buccal root anatomy and this was speculated to be due to the smaller FOV size and voxel size (15). The results of our study do not agree with this speculation regarding voxel size. However, the smallest FOV systems (3D Accuitomo 80, Veraviewepocs 3D R100) identified a greater number of apical exits. No significant difference was found between the 5 systems studied and microCT in the ability to identify the presence of MB2 in maxillary molars.

Pinto et al in 2021 compared 10 different CBCT systems: 3D Accuitomo 170 (J. Morita), Veraview X800 (J. Morita), X1 (3Shape), NewTom VGi evo (Cefla Dental Group), OP 3D Pro (Instrumentarium), OP 3D (Instrumentarium), CS 9300 (Carestream), ProMax 3D Max (Planmeca), Orthophos SL 3D (Dentsply Sirona), and Spectral Dental UEG (UEG Medical) (22). The systems were ranked from best to worst based on the detection of a narrow canal, isthmus, and an apical dental ramification using one phantom mandible with no metal, and a second phantom with an endodontically treated premolar with metal post and amalgam restoration (22). The best device performance was found to be dependent on the presence of metal (22). When metal was not present in the phantom sample, the Veraview X800 scored the highest in all 3 tasks; however, when metal was present, the 3D Accuitomo 170 scored best, though this was not statistically significant from the NewTom VGi evo system (22). Our present study found that the two J. Morita systems studied, 3D Accuitomo 80 and the Veraviewepocs 3D R100, detected the greatest number of apical exits or ramifications but were less accurate in determining whether MB2 joined MB1. We did not evaluate accuracy based on or control for the presence of metal or other restorations that may cause radiographic artifacts. Samples were allowed to have ceramic and metal restorations. This may be an area to evaluate in the future.

Limitations of this study include the scanning parameters for each of the CBCT systems which were different with varying FOV, voxel size, kVp, mA, and scan time. Each system was evaluated in the corresponding viewing software as a clinician is likely to view a CBCT in the same software brand as the capturing system. The features of each viewing software system such as filters, resolution, ease of use, and compatibility were not assessed as part of this study. A future study using the same DICOM images in the different viewing software systems may answer whether the software plays a significant role in accurately diagnosing maxillary molar anatomy by better controlling for image quality factors such as radiographic artifacts, reconstruction techniques, exposure settings, dose, filters, contrast, and restorations. Another limitation of this study is that it was completed *in situ* and did not use a human skull. This may influence the amount of noise and resolution of images when viewing the molar anatomy.

## CONCLUSION

While Micro-CT was significantly better for identifying apical anatomy than all CBCT systems, the CBCT systems studied were found to be highly accurate in MB2 identification. The 3D Accuitomo 80 and Veraviewepocs D R100 were significantly different from micro-CT for visualizing whether MB2 joined MB1. Among CBCT machines evaluated, 3D Accuitomo 80 better identified the number of apical exits than did iCAT FLX, Carestream CS9300 and Planmeca ProMax 3D Max, but was not significantly different from Veraviewepocs 3D R100.

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*The opinions or assertions contained herein are the private ones of the author(s) and are not to be construed as official or reflecting the view of the DoD or USUHS.*

*The authors deny any conflicts of interest related to this study.*

## REFERENCES

1. Hess W, Zürcher E. The anatomy of the root-canals of the teeth of the permanent dentition. New York, NY: William Wood and Company; 1925.
2. Weine FS, Healey HJ, Gerstein H, Evanson L. Canal configuration in the mesiobuccal root of the maxillary first molar and its endodontic significance. *Oral Surg Oral Med Oral Pathol* 1969;28(3):419-425.
3. Vertucci FJ. Root canal anatomy of the human permanent teeth. *Oral Surg Oral Med Oral Pathol* 1984;58(5):589-599.
4. Martins JNR, Marques D, Silva E, Caramês J, Mata A, Versiani MA. Second mesiobuccal root canal in maxillary molars - a systematic review and meta-analysis of prevalence studies using cone beam computed tomography. *Arch Oral Biol* 2020;113:104589.
5. Gilles J, Reader A. An SEM investigation of the mesiolingual canal in human maxillary first and second molars. *Oral Surg Oral Med Oral Pathol*. 1990;70(5):638-643. doi:10.1016/0030-4220(90)90415-o
6. Kulild JC, Peters DD. Incidence and configuration of canal systems in the mesiobuccal root of maxillary first and second molars. *J Endod*. 1990;16(7):311-317. doi:10.1016/s0099-2399(06)81940-0
7. Wolcott J, Ishley D, Kennedy W, Johnson S, Minnich S, Meyers J. A 5 yr clinical investigation of second mesiobuccal canals in endodontically treated and retreated maxillary molars. *J Endod*. 2005;31(4):262-264. doi:10.1097/01.don.0000140581.38492.8b

8. Baruwa AO, Martins JNR, Meirinhos J, Pereira B, Gouveia J, Quaresma SA, et al. The influence of missed canals on the prevalence of periapical lesions in endodontically treated teeth: a cross-sectional study. *J Endod* 2020;46(1):34-39.e31.
9. Stropko JJ. Canal morphology of maxillary molars: clinical observations of canal configurations. *J Endod* 1999;25(6):446-450.
10. Buhrey LJ, Barrows MJ, BeGole EA, Wenckus CS. Effect of magnification on locating the MB2 canal in maxillary molars. *J Endod* 2002;28(4):324-327.
11. Studebaker B, Hollender L, Mancl L, Johnson JD, Paranjpe A. The incidence of second mesiobuccal canals located in maxillary molars with the aid of cone-beam computed tomography. *J Endod* 2018;44(4):565-570.
12. Aung NM, Myint KK. Diagnostic accuracy of CBCT for detection of second canal of permanent teeth: a systematic review and meta-analysis. *Int J Dent* 2021;2021:1107471.
13. Vizzotto MB, Silveira PF, Arús NA, Montagner F, Gomes BP, da Silveira HE. CBCT for the assessment of second mesiobuccal (MB2) canals in maxillary molar teeth: effect of voxel size and presence of root filling. *Int Endod J* 2013;46(9):870-876.
14. AAE and AAOMR joint position statement: use of cone beam computed tomography in endodontics 2015 update. *J Endod* 2015;41(9):1393-1396.
15. de Freitas JV, Baratto-Filho F, Coelho BS, Tomazinho FSF, Crozeta BM, de Sousa Neto MD, et al. Efficacy of different cone-beam computed tomographic protocols in the identification of mesiobuccal canals of maxillary first molars: a tomographic and ex vivo study. *J Endod* 2017;43(5):810-815.
16. Schropp L, Alyass NS, Wenzel A, Stavropoulos A. Validity of wax and acrylic as soft-tissue simulation materials used in in vitro radiographic studies. *Dentomaxillofac Radiol* 2012;41(8):686-690.
17. Ren H, Chen J, Deng F, Zheng L, Liu X, Dong Y. Comparison of cone-beam computed tomography and periapical radiography for detecting simulated apical root resorption. *Angle Orthod* 2013;83(2):189-195.
18. Neves FS, Vasconcelos TV, Vaz SL, Freitas DQ, Haiter-Neto F. Evaluation of reconstructed images with different voxel sizes of acquisition in the diagnosis of simulated external root resorption using cone beam computed tomography. *Int Endod J* 2012;45(3):234-239.
19. Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33(1), 159–174.
20. Setzer FC, Hinckley N, Kohli MR, Karabucak B. A survey of cone-beam computed tomographic use among endodontic practitioners in the United States. *J Endod* 2017;43(5):699-704.
21. Alzamzami ZT, Abulhamael AM, Talim DJ, Khawaji H, Barzanji S, Roges RA. Cone-beam computed tomographic usage: survey of American endodontists. *J Contemp Dent Pract* 2019;20(10):1132-1137.
22. Pinto JC, Wanderley VA, de Faria Vasconcelos K, Leite AF, Pauwels R, Nadjmi M, et al. Evaluation of 10 cone-beam computed tomographic devices for endodontic assessment of fine anatomic structures. *J Endod* 2021;47(6):947-953.
23. Deliga Schröder AG, Westphalen FH, Schröder JC, Fernandes Â, Ditzel Westphalen VP. Accuracy of different imaging CBCT systems for the detection of natural external radicular resorption cavities: an ex vivo study. *J Endod* 2019;45(6):761-767.

24. Strobel S, Lenhart E, Woelber JP, Fleiner J, Hannig C, Wrbas KT. Comparison of two cone-beam computed tomography systems in the visualization of endodontic structures. *Swiss Dent J* 2017;127(3):221-229.
25. Alqerban A, Jacobs R, Fieuws S, Nackaerts O, Willems G. Comparison of 6 cone-beam computed tomography systems for image quality and detection of simulated canine impaction-induced external root resorption in maxillary lateral incisors. *Am J Orthod Dentofacial Orthop* 2011;140(3):e129-139.
26. Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Comparison of five cone beam computed tomography systems for the detection of vertical root fractures. *J Endod* 2010;36(1):126-129.
27. Dantas LL, Ferreira PP, Oliveira L, Neves FS, Campos P, Scarfe WC, et al. Cone beam computed tomography devices in the evaluation of buccal bone in anterior teeth. *Aust Dent J* 2019;64(2):161-166.
28. Elsaltani MH, Farid MM, Eldin Ashmawy MS. Detection of simulated vertical root fractures: which cone-beam computed tomographic system is the most accurate? *J Endod* 2016;42(6):972-977.
29. Vaz de Souza D, Schirru E, Mannocci F, Foschi F, Patel S. External cervical resorption: a comparison of the diagnostic efficacy using 2 different cone-beam computed tomographic units and periapical radiographs. *J Endod* 2017;43(1):121-125.
30. Khademi, A., Saatchi, M., Sheikhi, M., Soltani, M. M., & Moradi, S. (2022). In vitro diagnostic accuracy and agreement of dental microscope and cone-beam computed tomography in comparison with microcomputed tomography for detection of the second mesiobuccal canal of maxillary first molars. *Scanning*, 2022, 1493153.
31. Mouzinho-Machado S, Rosado LPL, Coelho-Silva F, Neves FS, Haiter-Neto F, de-Azevedo-Vaz SL. Influence of voxel size and filter application in detecting second mesiobuccal canals in cone-beam computed tomographic images. *J Endod* 2021;47(9):1391-1397.