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Original Article

Accuracy of Cone-Beam Computed Tomography Software in Predicting the Size of Impacted Canine: A Preliminary Study

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Main Points
- This study aims to compare and analyze the Precision & Accuracy of four CBCT software programs used in predicting the mesiodistal diameter of impacted canine and its reliability was compared with measurements made by digital vernier caliper.
- There were no clinical (in vivo) studies have been conducted to assess the accuracy and reliability of CBCT software.
- Every year many software programs have been introduced. Hence, it is highly essential to evaluate software programs for accuracy and reliability before they are implemented for medical practice.

ABSTRACT

Objective: To compare and analyze the precision, accuracy, and reliability of commonly used cone-beam computed tomography (CBCT) software in predicting the mesiodistal diameter of impacted canines.

Methods: This study was conducted on 11 patients (six males and five females, mean age: 17.5±5.5 years) with either unilateral or bilateral impacted canines in the maxilla or mandible. DICOM data sets of the patients obtained from CBCT scans were then loaded and visualized with four selected CBCT software to measure the widest mesiodistal diameter of the impacted teeth. Physical measurements using a digital vernier caliper, kept as a control, were also made on the extracted teeth and orthodontically erupted teeth. The collected data underwent statistical analysis, and the statistical significance level was set at $p<0.05$.

Results: The Bland-Altman analysis was performed to quantify the agreement between different software to the digital caliper, showing a narrow difference for all plots. Kruskal-Wallis ANOVA test followed by a post hoc test was performed to determine whether there was any difference in measuring the mesiodistal diameter of the impacted canine among the five methods, and tend no statistically significant difference was found among the five methods. Intraclass correlation (ICC) was performed, and measurements made with all CBCT software yielded an ICC greater than 0.95, indicating high reliability of the selected software.

Conclusion: All the evaluated CBCT imaging software exhibited a high degree of reliability, and accuracy in precise measurement of the mesiodistal diameter of an impacted tooth.

Keywords: Cone-beam computed tomography, software validation, data accuracy, tooth, impacted canine

INTRODUCTION

Predicting the size of unerupted or impacted teeth is one of the notable challenges in orthodontic practice for precise diagnosis and treatment planning. The variation between the space needed for the dentition and space available in the dental arch will lead to crowding or spacing,[1] consequently, an accurate estimation of the mesiodistal diameter (MDD) of the erupting permanent teeth is necessary to decide whether sufficient space is available for the permanent teeth to erupt correctly. Furthermore, it plays a vital role in determining eruption guidance, space maintenance, space regaining, or extraction during orthodontic treatment planning.

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Generally, the prediction of the MDD of unerupted permanent teeth is made either through direct measurements of unerupted tooth size on radiographs,[2] calculations from prediction equations, and tables,[3-5] or a combination of both methods.[6-8] For this purpose, numerous radiographic techniques have been suggested, such as periapical X-rays with central beam deviation (Clark's technique), occlusal, and panoramic radiographs.[2,6-8] However, several drawbacks of two-dimensional images in the visualization of unerupted teeth are challenging to differentiate the exact location of the teeth, impact on adjacent teeth/structures that cannot be accurately visualized, image distortions, image superimposition, artifacts, etc.[9] To overcome these glitches, conventional computed tomography (CT) scanning is sometimes used. However, this diagnostic aid is not highly recommended due to high radiation exposure during the procedure.[10]

Taking these considerations into account, cone-beam computed tomography (CBCT) is now commonly used in orthodontic practice for accurate diagnosis, especially in cases involving impacted teeth because it provides 3-Dimensional perspective at high resolution than conventional dental radiographs and provides better visualization of hard-tissue images than conventional CT images.[10-12]

Numerous software programs have been introduced every year to interpret and analyze Digital Imaging Communications in Medicine (DICOM) images. Hence, it is essential to evaluate software programs for accuracy and reliability before they are implemented for medical practice. However, thus far, no clinical (*in vivo*) studies have been conducted to assess the accuracy and reliability of CBCT software. Therefore, this study compares and analyzes the precision and accuracy of four CBCT software programs used in predicting the MDD of an impacted canine. Its reliability was compared with measurements made by a digital vernier caliper.

METHODS

Eleven patients (6 males and 5 females, mean age of 17.5±5.5 years) who were seeking orthodontic treatment with either unilateral or bilateral impacted canines in maxilla or mandible were selected for this study. Out of 11 patients, 4 patients had bilaterally impacted canines (for a total sample of 15 impacted canines). Informed consent was obtained from all selected patients, and the Institutional Review Board of Ragas Dental College and Hospital approved the study protocol (reference number: 201206IRB8 and the date: 12.06.2012).

CBCT imaging was used as part of the routine investigations to locate the impacted canine in three dimensions. The standardized scanning parameters were set to 5.0 mA, 120 Kv, 0.3 mm voxel size, and 9.6 second exposure time. After a comprehensive analysis based on the prognosis and severity of impaction,[13] the impacted teeth were either extracted or orthodontically brought into occlusion.

Nine impacted canines in 7 patients were extracted due to their unfavorable position and poor prognosis. Meticulous care was taken during the extraction to avoid any damage or alteration of crown morphology. One tooth was excluded from this study due to enamel fracture during extraction. A digital vernier caliper measured the extracted tooth widest MDD. Likewise, six impacted canines in 4 patients were surgically exposed and brought into occlusion byorthodontic treatment. After a complete eruption, the widest MDD of an erupted tooth was measured using the same digital vernier caliper.

To allow calculation of arithmetic means and avoid associated errors, all measurements made through a digital vernier caliper (Nominal resolution: ± 0.01 mm) were performed by a single investigator measured thrice with an interval of one week apart. Furthermore, intraclass correlation (ICC) to examine the intraexaminer reliability was calculated and found to be high with the ICC values ranging from 0.997 to 1. The physical measurement values were considered a control.

All DICOM images from CBCT scanning were uploaded separately into the four CBCT software. CBCT imaging software programs used in this study are:

1. Mimics software (Version 10.01; Materialise, Leuven, Belgium) (Figure 1):

Materialise Interactive Medical Image Control System (Mimics) was the first software to import DICOM files. Mimics have been used to set the sagittal (y-axis), vertical (z-axis), and transverse (x-axis) planes for three-dimensional image construction. After verification of three orthogonal views, landmarks were identified to quantify image variables of impacted canines.

2. Dolphin 3D software (Version 11.7; Dolphin Imaging & Management Solutions, Chatsworth California) (Figure 2):

Dolphin Imaging is the most often used reconstruction program for CBCT imaging. Three planes, namely axial, coronal, and sagittal, have been used to reduce errors and relocate the images according to head position orientation while calculating volume sections of the impacted canine.

Figure 1. Mimics software (Version 10.01; Materialise, Leuven, Belgium)

3. OsiriX software (Version 3.8.3; Pixmeo, Geneva, Switzerland) (Figure 3):

OsiriX is an image processing application for the Mac operating system. DICOM files were loaded to assess the position of the canine and surrounding teeth in the multi-planar reconstruction planes. Images were magnified five times to delineate the tooth structure of an impacted tooth at a higher resolution to avoid calibration errors.

4. CS 3D Imaging software (Version 3.2.9; France) (Figure 4):

The CS 3D Imaging software is a user-friendly tool that includes advanced functions and applications to increase diagnostic and treatment planning capabilities. This software allows for the localization of impacted canines with a different interest viewpoint, such as axial, coronal, and sagittal using spatial relationships with excellent tissue contrast.

The 3D images of impacted teeth for each patient were visualized in three planes including axial, coronal, and sagittal. Then, the best-visualized plane to measure the maximum MDD of an impacted canine was identified according to the positional orientation of the impacted canine. Subsequently, to compute the widest MDD, the image of each tooth of interest was oriented perpendicular to the occlusal plane by extrapolating the 2-dimensional and 3D images simultaneously (Figure 5). After identifying and measuring the widest MDD in a particular slice, two more measurements were taken with one slice before

Figure 3. OsiriX software (Version 3.8.3; Pixmeo, Geneva, Switzerland)

Figure 2. Dolphin 3D imaging software (Version 11.7; Dolphin Imaging & Management Solutions, Chatswort California)

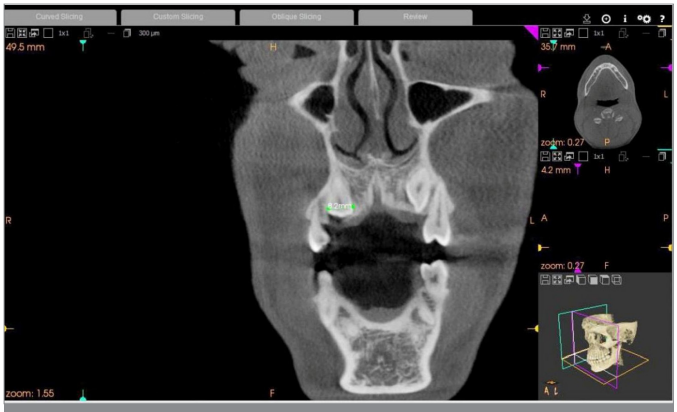


Figure 4. CS 3D Imaging software (Version 3.2.9; France)

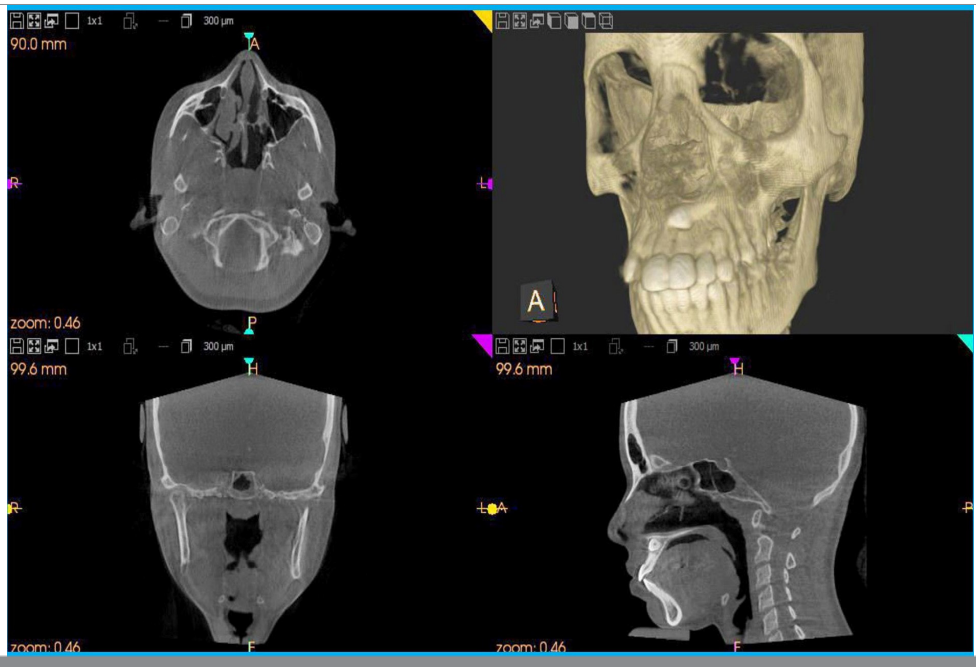


Figure 5. 3-Dimensional (3D) volume visualization displayed along with 2-Dimensional visualization

and one after the selected slice (slice thickness=0.3 mm). Consequently, the mean of these three values was considered as the maximum MDD of that particular tooth.

Statistical Analysis

The data obtained, were statistically analyzed using SPSS (version 19.0; IBM Corp., Armonk, NY, USA). Descriptive statistics for the mean difference and standard deviations were calculated for all variables. The Bland-Altman graph was quantify the agreement between two quantitative measurements by constructing limits of agreement between different software and the gold standard (digital caliper). Kruskal-Wallis ANOVA followed by a post-hoc test was used to compare the variables between the groups. ICC was performed to assess the reliability between the four CBCT software programs and a digital vernier caliper. The statistical significance level was set at $p<0.05$.

RESULTS

The widest MDDs of 14 impacted canines were measured. Mean differences and standard deviations were calculated for all variables. The Bland-Altman analysis was plotted to verify the extent of agreement or disagreement between different software and the gold standard (digital caliper) (Graph 1).

Bland-Altman plot compared two assay methods: software and digital caliper. It plotted the difference between the measurements of software and digital caliper on the y-axis, and the mean of the two measurements on the X-axis. Bland-Altman analysis generated two pages of results. The first page shows the difference and mean values of the two measurements, that were used to generate the plot. The second page shows the bias and standard deviation.

Bland-Altman plot-Digital caliper and Mimics: The graph shows that there is only a narrow difference, and it is within the limits of agreement for both methods. However, as the mean increases, the difference tends to increase as well, as depicted in Graph 1*.

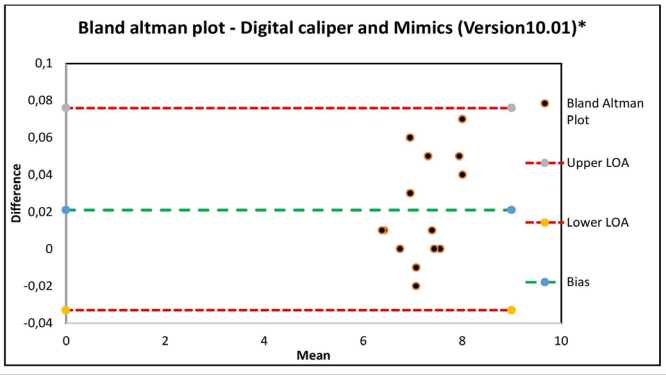
Bland-Altman plot-Digital caliper and Dolphin Imaging: The graph shows that there is only a narrow difference between the upper and lower lines of the agreement, which is depicted by being mostly above the bias line. However, the difference tends to be higher as most of the plots are above the bias line, as shown in Graph 2*.

Bland-Altman plot-Digital caliper and OsiriX: The graph shows that the difference is narrow and seems within the limit of agreement, which is similar to the other methods and further most since the plots are above the Bias line. This shows that the difference is greater than the mean of 7 (Graph 3)*.

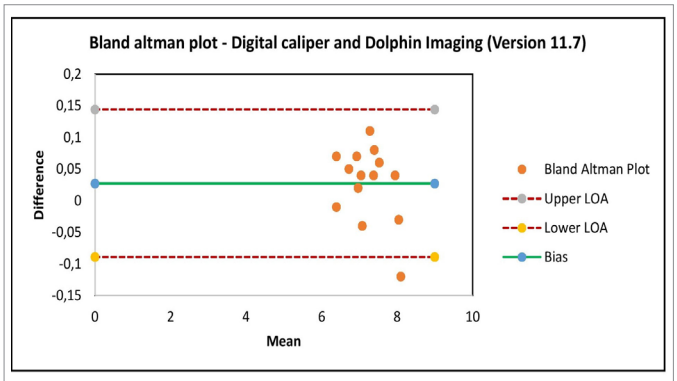
Bland-Altman plot-Digital caliper and CS 3D Imaging: The graph shows that there is a slightly wide difference between the lines of agreement. Most of the plots are near or precisely above the line, indicating a higher difference between both the methods (Graph 4)*.

From Graph 1, the limits of agreement for Mimics, Dolphin, OsiriX and CS 3D Imaging were 0.1, 0.2, 0.2, 0.3 respectively. The results obtained from Graph 1 show that for OsiriX and CS 3D Imaging software, most of the difference between the software and digital caliper were positive. The mean-positive differences in OsiriX and CS 3D Imaging were 0.0325 and 0.0688 respectively.

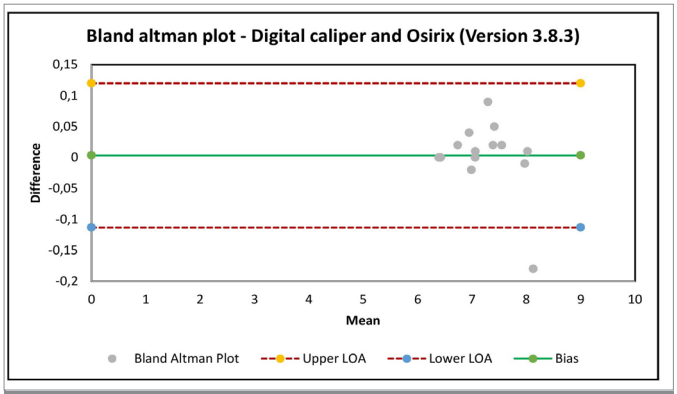
A Kruskal-Wallis ANOVA test was performed to compare and determine whether there were any differences in measuring the MDD of the impacted canine among the five methods (Table 1). The results revealed no statistically significant differences among all the five methods.



Graph 1. Bland altman plot - Digital caliper and Mimics (Version 10.01)



Graph 2. Bland altman plot - Digital caliper and Dolphin Imaging (Version 11.7)



Graph 3. Bland altman plot - Digital caliper and OsiriX (Version 3.8.3)

A post-hoc test was used to analyze inter-group comparison of the MDD of the impacted canine using each software and the gold standard method. This indicated that the comparison of all five groups agreed with these results and showed no statistically significant difference among all five methods (Table 2).

ICC was performed to assess the reliability between the four CBCT software programs and a digital vernier caliper (Table 3). The range of ICC values was from 0 to 1, with values close to 1 indicating strong evidence of reproducibility, and values close to 0 indicating less reproducibility. All CBCT software programs yielded an ICC greater than 0.95, indicating the high reliability of the selected software, with Mimics software (ICC: 0.999) having the highest correlation with the digital vernier caliper.

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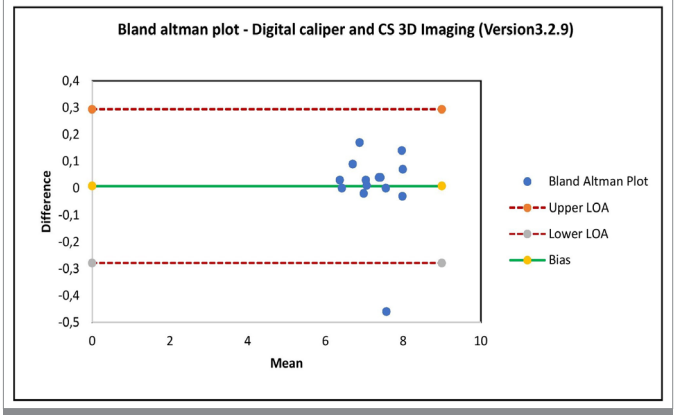
DISCUSSION

Moyers[4] reported that overestimation of 1 mm above the actual widths of permanent canines and premolars would unfavorably influence the decision of extraction or non-extraction. Conversely, Proffit and Ackerman[9] suggested that an error of 1.5 mm is acceptable in expressing the error in tooth size prediction, and anything exceeding this is considered. However, significant variations in tooth size prediction can create problems and must be incorporated in the orthodontic problem list. Hence, the clinical significance in predicting unerupted tooth size becomes more critical.

To overcome the inadequacies and limitations of various prediction methods, CBCT was recommended toprecisely locate and accurately predict the MDD of an impacted tooth.[14] Walker et al.[15] established reference lines on anatomic landmarks in 2005 for three-dimensional localization of maxillary canines with CBCT. He also stated that 3D volumetric imaging systems precisely localization of impacted canines.[15]



Graph 4. Bland altman plot - Digital caliper and CS 3D Imaging (Version 3.2.9)

Table 1. Comparison of mesiodistal diameters measured by five methods using Kruskal-Wallis test

Group	Mean±SD	p value
Digital Vernier Caliper	7.24±0.54	0.99
Mimics	7.22±0.52	
Dolphin 3D	7.21±0.56	
OsiriX	7.24±0.56	
CS 3D Imaging	7.23±0.56	
Total	7.23±0.53	

Level of significance, p value<0.05.

Table 2. Inter-group comparison of mesiodistal diameters using post-hoc analysis

Group		Mean±SD	p value
Digital Vernier Caliper	Mimics	0.02±0.20	1.0
	Dolphin 3D	0.02±0.20	
	OsiriX	0.00±0.20	
	CS 3D Imaging	0.00±0.20	
Mimics	Digital Vernier Caliper	-0.02±0.20	
	Dolphin 3D	0.00±0.20	
	OsiriX	-0.01±0.20	
	CS 3D Imaging	-0.01±0.20	
Dolphin 3D	Digital Vernier Caliper	-0.02±0.20	
	Mimics	-0.00±0.20	
	OsiriX	-0.02±0.20	
	CS 3D Imaging	-0.01±0.20	
OsiriX	Digital Vernier Caliper	-0.00±0.20	
	Mimics	0.01±0.20	
	Dolphin 3D	0.02±0.20	
	CS 3D Imaging	0.00±0.20	
CS 3D Imaging	Digital Vernier Caliper	-0.00±0.20	
	Mimics	0.01±0.20	
	Dolphin 3D	0.01±0.20	
	OsiriX	-0.00±0.20	

Level of significance p value<0.05; SD, Standard deviation.

Table 3. Reliability between various softwares and digital caliper

Software vs. Physical Measurement	Intraclass Correlation	95% CI	
		Lower bound	Upper bound
MIMICS (version 10.01)	0.99	0.99	1.00
DOLPHIN 3D (version 11.7)	0.99	0.98	0.99
OSIRIX (version 3.8.3)	0.99	0.98	0.99
CS 3D (version 3.2.9)	0.96	0.89	0.98

CI, confidence interval.

The Bland-Altman plot shows that limits of agreement for Mimics were narrower than 0.1, indicating a greater precision. Dolphin and OsiriX limits of agreement were greater than 0.1, but narrower than 0.2, which could still be acceptable clinically. However, CS 3D Imaging was around 0.3, indicating poor precision associated with this software for this specific measure. From the result obtained from Graph 1, most of the differences were positive in OsiriX (0.0325) and CS 3D Imaging software (0.0688), which could be clinically acceptable. This result may be due to the underestimation of measurements by the software. Obviously, the sample size is small and the findings should be validated in future research.

The present study results reveal that all four CBCT software programs have high accuracy in predicting the impacted tooth's MDD. The mean MDD of impacted canine measured by digital vernier caliper (physical method) was equivalent to the mean MDD measured by all four CBCT software (digital method). Besides, the difference invalues between the four CBCT software ranges from 0.01 to 0.02. These values were statistically insignificant (p>0.05).

Moreover, the present study results revealed that CBCT methods tended to overestimate the MDD of the impacted tooth by 0.015 mm, but it is not clinically noteworthy. These results were analogous to a study by Sakabe et al.[16], who concluded that the measurements on the 3DX images overestimate a mesiodistal tooth diameter by 0.088 mm.[16] In contrast, Nguyen et al.[14] found that CBCT methods underestimate MDD by 0.4 mm.[13]

The ICC results of this study revealed high correlations (>0.95) between all four CBCT softwareprograms and the digital vernier caliper, which indicates that either of these CBCT software programs can accurately reproduce the dimensions of impacted teeth. Furthermore, among all these four CBCT software, the ICC test revealed that Mimics software was the most reliable (ICC: 0.999) compared to the physical method (Table 3).

Earlier, predictions of impacted tooth size were made by methods such as Moyers[4] prediction table, Tanaka and Johnston's[5] equation, etc. However, all these methods had limitations, as they were conducted with children from Northwestern European ancestry.[4,5] Therefore, the reliability of applying this methodology in other populations was questionable as tooth sizes differ within different population groups.[17,18] However, prediction methods using CBCT eradicate this population variations and are highly reliable because measurements are made individually with a precise 1:1 ratio and conflicting tables of average tooth sizes or regression models are avoided. In contrast to this study, Hofmann et al.[19] compared the imaging accuracy of CBCT data with multislice spiral computed tomography (MSCT) data sets for predicting the exact mesiodistal width of unerupted porcine tooth germs. They concluded that MSCT outperforms CBCT regarding determining tooth width.[19]

One constraint related to CBCT scanning is radiation exposure. Grünheid et al.[20] in 2012 compared the dosimetry of a CBCT with a digital X-ray in orthodontic imaging. They concluded that even though CBCT provides additional diagnostic and therapeutic benefits, patients are exposed to higher radiation levels than conventional digital radiography.[20] However, Hodges et al.[21] analyzed CBCT use in orthodontic diagnosis and treatment planning in 2013. They specified that obtaining a CBCT scan before orthodontic diagnosis and treatment planning is essential for patients with unerupted teeth due to uncertain location, as frequent modification is noted during orthodontic diagnosis and treatment planning.[21] In 2016, Detterbeck et al.[22] compared the accuracy of mesiodistal width measures with MRI to traditional 3D imaging techniques (MSCT, CBCT, and CT). The study concluded that magnetic resonance imaging (MRI) seems to be clinically equivalent to conventional ionizing 3D imaging techniques, and tooth germs are better appreciated than erupted teeth on MRI with less radiation exposure.[22] The smaller sample sizes can be considered a limitation of this study. Hence, further studies with a larger sample size are warranted to validate the reliability of CBCT software.

CONCLUSION

From the results obtained, it is prudent to conclude that there is no statistically significant difference between the measurements made using CBCT software and the digital vernier caliper. Furthermore, all four CBCT software programs revealed a high degree of reliability compared to the digital caliper.

Ethics

Ethics Committee Approval: The Institutional Review Board of Ragas Dental College and Hospital approved the study protocol (reference number: 201206IRB8 and the date: 12.06.2012).

Informed Consent: Informed consent was obtained from all selected patients.

Peer-review: Internally peer-reviewed.

Author Contributions: Concept - M.D., S.H.F., K.N.R.; Design - M.D., S.H.F., K.N.R.; Data Collection and/or Processing - M.D., S.H.F., K.N.R.; Analysis and/or Interpretation - M.D., S.H.F., K.N.R.; Literature Review - M.D., S.H.F., K.N.R.; Writing - M.D., S.H.F., K.N.R.

Declaration of Interests: The authors have no conflicts of interest to declare.

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