Comparative analysis of traditional radiographs and cone-beam computed tomography volumetric images in the diagnosis and treatment planning of maxillary impacted canines

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Introduction: In this prospective study, we compared differences in the diagnosis and treatment planning of impacted maxillary canines between 2 imaging modalities. Methods: Twenty-five consecutive impacted maxillary canines were identified from the pool of patients seeking orthodontic treatment. The first set of radiographs consisted of traditional 2-dimensional (2D) images including panoramic, occlusal, and 2 periapical radiographs. The second set comprised prints of 3-dimensional (3D) volumetric dentition images obtained from a cone-beam computed tomography (CBCT) scan. Seven faculty member completed a questionnaire for every impacted canine and diagnostic radiographic modality (2D and 3D).

Results: The data show that the judges produced different decisions regarding localization depending on the x-ray method. There were 21% disagreement (or discordance) in the perceived mesiodistal cusp tip position and 16% difference in the perceived labiopalatal position. In the perception of root resorption of adjacent teeth, there was 36% lack of congruence. Twenty-seven percent of the teeth that were planned to be left, recovered, or extracted with the 2D radiographs had different treatment plans when the judges viewed the 3D CBCT images (McNemar test, chi-square, 4.45; \( P = 0.035 \)). The clinicians’ confidence of the accuracy of diagnosis and treatment plan was statistically higher for CBCT images \( P < 0.001 \).

Conclusions: These results showed that 2D and 3D images of impacted maxillary canines can produce different diagnoses and treatment plans. (Am J Orthod Dentofacial Orthop 2010;137:590-7)

Most permanent teeth erupt into occlusion un-assisted. Occasionally, some permanent teeth become impacted and fail to erupt. This situation often requires intervention by both an orthodontist and an oral and maxillofacial surgeon. The decision for interceptive treatment takes into account several factors, including how to expose, recover, extract, or not treat. Some factors include location of the impaction, prognosis of intervention on the impacted tooth and adjacent teeth, surgical accessibility, impact of treatment on the final functional occlusion, and possible surgical morbidity. This treatment decision has traditionally been based on planar 2-dimensional (2D) radiographs.\(^1\text{-}^{11}\) Medical technology offers 3-dimensional (3D) volumetric images, but these are expensive and expose patients to higher doses of radiation.\(^12\text{-}^{15}\) New imaging techniques are now available in dentistry with cone-beam computed tomography (CBCT), which provides low radiation, rapid image scanning with radiographic and 3D volumetric data for each patient.\(^16\text{-}^{20}\) This 3D technology will improve the dental provider’s ability to diagnose and treat patients with impacted teeth. In this study, we
aimed to determine if using 2 imaging modalities, 2D and 3D systems, would result in a different diagnosis or a different treatment plan for impacted maxillary canines.

The maxillary canine is the second most commonly impacted tooth, after the third molars. The reported incidence ranges from 0.8% to 2.8%, depending on the population examined.\(^\text{21-24}\) It has been reported that the incidence of impaction is twice as likely in female patients.\(^\text{23}\) Even though maxillary canine tooth buds develop labially to adjacent tooth roots, the ratio of palatal impactions to labial impactions is at least 3:1.\(^\text{25}\) Other investigators have found impacted canines to be positioned palatally 85% of the time compared with labial positioning 15% of the time.\(^\text{8,10,11,26}\)

Proper localization of an impacted tooth is required to make an accurate diagnosis, determine proper surgical access, and plan the direction of orthodontic recovery forces. In the past, diagnostic radiographs included periapical, occlusal (normal and topographic), and panoramic radiographs. In orthodontics, knowing the exact location of an impacted canine is paramount, since the decision about whether it should be exposed, extracted, recovered, or left untreated influences the treatment plan.

For a labial impaction, the tooth can often be located by palpation. If the tooth is positioned in the middle of the alveolus or palatally, it is necessary to determine its labiopalatal location by taking 2 or more periapical radiographs at different horizontal angles. Clark’s rule enables the practitioner to determine the location of these impacted teeth.\(^\text{27}\) When radiographs are taken at different horizontal angulations of a pair of objects, the image of the palatal object moves in the same direction as the x-ray beam, whereas the labial object appears to move in the opposite direction. With this periapical film technique, the clinician can evaluate the labiopalatal position of the canine with sufficient accuracy in 92% of patients.\(^\text{10,11}\)

Additional radiographic images are often required to ascertain the exact location of an impacted tooth in all 3 dimensions. To aid in determining the vertical position and horizontal angulation, a panoramic radiograph is used. Normal occlusal or topographic occlusal radiographs help to determine the relative positions of adjacent teeth. In addition, they help to determine the labiopalatal position of the impacted canine in conjunction with the periapical films if the image of the impacted canine is not superimposed on other teeth.\(^\text{28}\) Frontal and lateral cephalograms often elucidate the proximity to other facial structures, such as the maxillary sinus and nasal floor.\(^\text{29}\)

Orthodontists and oral surgeons have always needed to precisely locate teeth and tissues in all 3 planes of space. To date, only planar radiographs have been available. 3D information has been available with medical x-ray computed tomography scanners, but limitations include exposure dose, cost, and access to CT imaging service providers. A new system, CBCT, has been developed and designed for 3D imaging of the craniofacial field.\(^\text{30,31}\) The unique feature of this system is that it uses a low-energy, fixed-anode tube, which produces a cone-shaped x-ray beam, a special image intensifier, and a solid-state sensor or an amorphous silicon plate for capturing the image. CBCT systems vary in their radiation, depending on the machine, the size of the radiated region, and the amounts of milliamps and kilovolts of the system, but the doses are lower than medical computed tomography systems.\(^\text{32}\)

CBCT images are inherently more accurate than traditional x-rays, since beam projection is orthogonal; this means that the x-ray beams are approximately parallel to one another, and the object is near the sensor. This explains why there is little projection effect and no magnification. In addition, the computer software addresses the projection effect, resulting in undistorted 1:1 measurements. This contrasts with traditional imaging, which always has some projection error because the anatomic regions of interest are at varying distances from the film. For example, panoramic radiographs have an unusual projection error because the main path of the x-ray beam comes from a slightly negative angulation. In this situation, the dental provider must account for these imaging artifacts when reading the images.

Another likely advantage of the CBCT scan is that the data acquired include information for the entire craniofacial region. Additional views such as lateral cephalograms, panoramic radiographs, occlusograms, airway evaluations, and volumetric images are available...
from the original acquisition data. These images can be manipulated with imaging software to aid the dental provider in diagnosis and treatment planning. The costs, efficiency, and benefits of CBCT imaging are favorable, because 1 imaging session can provide many views.30

MATERIAL AND METHODS

Eighteen consecutive patients (12 female, 6 male) with impacted maxillary canines were identified in the orthodontic clinic at the School of Dentistry, University of California at San Francisco. Twenty-five impacted canines were identified they included 7 bilateral impactions. Six canines were unilateral on the right, and 5 were unilateral on the left. The subjects ranged in age from 12.3 to 34.6 years (mean, 16.9 ± 5.8 years). Exclusion criteria included presence of deciduous teeth, craniofacial anomalies, incomplete root formation, and existing orthodontic appliances. For each subject, traditional 2D diagnostic radiographs and CBCT scans (Hitachi MercuRay, Hitachi Medical Technology, Tokyo, Japan) in digital imaging and communications in medicine (DICOM) format were obtained.

The 2D traditional radiographs included a panoramic radiograph to evaluate the vertical position, an occlusal x-ray to evaluate the proximity to adjacent teeth, and 2 periapical radiographs (Fig 1) to determine the labio-palatal position. Volumetric images of the maxillary dentition were obtained from a CBCT scan. CBWorks software (CyberMed, Seoul, Korea) was used for the segmentation process. The volume operation and sculpt features eliminated all soft tissues and hard tissues except the maxillary dentition (Fig 2). One operator (E.H.) performed segmentation of the maxillary dentition. Three-dimensional images included anterior, posterior, rostral-caudal, caudal-rostral, labial, and palatal views. The images were illustrated on 1 sheet of glossy photo paper (Epson, Long Beach, Calif). All identifying
patient information was removed, including name, sex, age, and race. The institutional review board of the University of California at San Francisco, the Committee on Human Research, approved this study. Informed consent to participate in this study was obtained from each subject or, for minors, a guardian.

The presentation of the impacted maxillary canines was ordered with a random number generator (www.randomizer.org). In addition, 5 impacted maxillary canines were randomly selected for replicates and were interspersed randomly to be evaluated a second time to determine intraoperator reliability. A total of 60 stations were prepared; they included 30 sets of traditional 2D radiographs and 30 CBCT 3D volumetric renderings.

Seven faculty members participated in the study: 4 orthodontists (including J.H. and E.J.) and 3 oral surgeons (including J.S.L.); 4 had less than 10 years of clinical experience, and 3 had more. All impacted canines were evaluated in one session. Before starting, each judge reviewed the questionnaire as part of the calibration process. At each station, the judge was asked to complete the questionnaire for that tooth. Each clinician was randomly assigned a starting point. The time to complete all 60 questionnaires ranged from 1.5 to 2.5 hours.

After collection, the data were analyzed by using StatView (version 5, SAS Institute, Cary, NC) to evaluate differences between traditional radiographs and CBCT volumetric renderings. Statistical analyses were performed, accounting for the clustering in patients, by using SAS software (version 9.1.2). Repeated measures tests were used to examine the different results between the 2 methods. The combined methods, traditional 2D radiographs and 3D CBCT volumetric views, had a range of agreement from 43% to 100% for each tooth. In 21% of the responses, there was a difference between the 2 methods. The combined methods, traditional 2D radiograph and 3D CBCT volumetric views, had a range of agreement from 43% to 100% for each tooth based on the 7 judges’ responses (14 total responses; Fig 5). There was 84% agreement for the labiopalatal position as assessed in 175 responses (Fig 5). The combined methods had a range of agreement from 50% to 100% for each tooth. Fifty percent of the teeth had 100% agreement, and 76% had one or no clinician in disagreement. However, there were no statistically significant differences between the 2D and 3D methods (chi-square test, P >0.5). There was 50% agreement when localizing the cusp in the vertical dimension.

In the diagnosis of root resorption, there was 64% agreement between the 2 methods as determined by the 7 judges (175 total responses; Fig 6). In the assessment of root resorption, the radiographic modality influenced the response (chi-square test, P <0.0001). The

### Table I. Intra-rater reliability, agreement, and kappa values

<table>
<thead>
<tr>
<th>Variable</th>
<th>2D and 3D</th>
<th>2D</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesiodistal location</td>
<td>0.76</td>
<td>0.92</td>
<td>0.61</td>
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<tr>
<td>Labiopalatal location</td>
<td>0.82</td>
<td>0.87</td>
<td>0.77</td>
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<tr>
<td>Vertical location</td>
<td>0.63</td>
<td>0.73</td>
<td>0.53</td>
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<tr>
<td>Root resorption</td>
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<td>0.73</td>
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<tr>
<td>Orthodontic treatment plan</td>
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<tr>
<td>Orthodontic treatment plan (recover)</td>
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<td>0.75</td>
<td>0.75</td>
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<tr>
<td>Orthodontic treatment plan (extract)</td>
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<tr>
<td>Number of recovery vectors</td>
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<tr>
<td>Second recovery vector</td>
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<td>Expect will erupt unassisted</td>
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<td>1.0</td>
<td>0.59</td>
</tr>
<tr>
<td>Expect additional root resorption</td>
<td>0.70</td>
<td>0.59</td>
<td>0.79</td>
</tr>
<tr>
<td>Request for additional images</td>
<td>0.62</td>
<td>0.46</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Kappa key: poor, 0.0-0.2; fair, 0.2-0.4; moderate, 0.4-0.6; substantial, 0.6-0.8; perfect, 0.8-1.0.

### Table II. Intra-rater reliability, Lin’s concordance

<table>
<thead>
<tr>
<th>Variable</th>
<th>2D and 3D</th>
<th>2D</th>
<th>3D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidence of diagnosis</td>
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<td>0.50</td>
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<tr>
<td>Confidence of treatment plan</td>
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<td>0.43</td>
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</table>

### RESULTS

There were differences in the identified location of the impacted cusp tip depending on the radiographic modality. For the mesiodistal tip position, there was 79% agreement among the 7 judges’ responses on 25 teeth (175 total responses; Fig 3) between the 2 methods. In 21% of the responses, there was a difference between the 2 methods. The combined methods, traditional 2D radiograph and 3D CBCT volumetric views, had a range of agreement from 43% to 100% for each tooth based on the 7 judges’ responses (14 total responses for each tooth; Fig 4). There was 84% agreement for the labiopalatal position as assessed in 175 responses (Fig 5). The combined methods had a range of agreement from 50% to 100% for each tooth. Fifty percent of the teeth had 100% agreement, and 76% had one or no clinician in disagreement. However, there were no statistically significant differences between the 2D and 3D methods (chi-square test, P >0.5). There was 50% agreement when localizing the cusp in the vertical dimension.

In the diagnosis of root resorption, there was 64% agreement between the 2 methods as determined by the 7 judges (175 total responses; Fig 6). In the assessment of root resorption, the radiographic modality influenced the response (chi-square test, P <0.0001). The
combined methods for a tooth were never unanimous (14 total responses per tooth) but, rather, ranged in agreement from 36% to 86%. In 8% of the cases, the mode was unsure in the diagnosis of root resorption and was positive in the diagnosis of root resorption for only one tooth.

The resulting orthodontic treatment plans, produced by only the 4 orthodontists, were significantly influenced...
by the radiographic modality ($P < 0.0001$). Twenty-seven percent of the teeth that were planned to be left, recovered, or extracted with the traditional 2D radiographs were selected for a different treatment when the judges viewed the 3D CBCT images (12 total responses; McNemar test, chi-square, 4.45; $P = 0.035$; Fig 7). The overall mode for an individual tooth was unanimous in 24% of the teeth, with a range of agreement from 50% to 100% on the other teeth. When comparing the responses of 2D with 3D, there was complete agreement on the orthodontic treatment plan in only 36% of the teeth, with only 1 clinician disagreeing in another 18% of the teeth.

If the treatment plan included recovery of the tooth, then the selection of the initial recovery vector was significantly influenced by the radiographic modality ($P < 0.0001$). Eleven of 12 teeth with an initial distal recovery vector with the 2D images had a different initial recovery vector with the 3D images. The judges’ decisions using the 2 methods for an individual tooth were unanimous in only 12% of the teeth, with a range of agreement from 50% to 100% on the other teeth. When comparing the responses of 2D with 3D, there was complete agreement on the orthodontic treatment plan in only 36% of the teeth, with only 1 clinician disagreeing in another 18% of the teeth.

A request for additional images to obtain a more accurate diagnosis was more likely with traditional radiographs (McNemar test, $P = 0.0016$). Sixty-one percent of the teeth had requests for additional images with 3D evaluations but not 2D. The overall mode of 2D and 3D images was unanimous for only 1 tooth, yet the mode for every tooth was that additional images were unnecessary, with a range of agreement from 50% to 100%.

For traditional radiographs, the means for the confidence of the diagnosis and treatment plan were both 8.6 on a scale from 1 to 10. For the CBCT images, the means for the confidence of the diagnosis and treatment plan were 9.4 and 9.2, respectively. The mean difference in the confidence of the diagnosis was 0.8 with a 1.3 SD. The mean difference in the confidence of the treatment plan was 0.6 with a 1.4 SD that was not significantly different.

The diagnosis of the labiopalatal position and the derived orthodontic treatment plan were influenced by tooth-to-tooth variations (Pearson chi-square test, $P < 0.0001$). Individual tooth-to-tooth variations also influenced the self-reported confidence of the diagnosis and the treatment plan when using CBCT images (Bonferroni [Dunn] t-test, $P = 0.050$ and $P = 0.003$, respectively). However, for the traditional radiographs, tooth-to-tooth variations did not significantly influence the clinicians’ confidence regardless of experience and specialty training. Tooth complexity suggests significance in relation to 3D confidence of diagnosis (analysis of variance [ANOVA], $P = 0.052$), whereas confidence of treatment plan is significantly related (ANOVA, $P = 0.003$). This implies that this confidence assessment is related to tooth-to-tooth variations.

**DISCUSSION**

This is one of the first studies to evaluate the clinical implications of using CBCT images for the diagnosis of
impacted maxillary canines compared against using traditional radiographs. While comparing the volumetric 3D method of CBCT and traditional 2D radiographs, we found differences between each method related to specific situations. Although not all were statistically significant, differences seem to exist for critical questions such as the labiopalatal position of the cusp tip. An interesting finding was the 84% agreement among clinicians on the labial or palatal tip position; the same lack of agreement was found when determining which side to start surgical access, implying that these 2 questions are directly related. The labiopalatal tip position is the most critical question for the surgeon when the tooth is to be removed or recovered. One could argue that, since fewer images were requested and the self reported confidence was significantly higher with CBCT images, this modality is superior. The surgeon is less likely to incorrectly access an impacted tooth, and the orthodontist is more likely to safely recover more impacted maxillary teeth.

Individual tooth variations affect the labiopalatal localization of the impacted canine. As expected, most impacted teeth can be accurately localized with traditional radiographs. However, this is not true for every impacted canine; some can be incorrectly localized, poorly accessed surgically, or recovered by using deleterious vectors. Ericson and Kurol demonstrated that 8% of impacted maxillary canines could not be accurately localized in the labiopalatal dimension with periapical radiographs. Bjerklin and Ericson showed that evaluating the same patients 10 to 12 months later with additional information from a computed tomography scan allowed them to detect root resorption in approximately 50% more incisors with retained and ectopically positioned maxillary permanent canines, and the treatment plan was changed for almost 44% of the patients.

Admittedly, in this study, we did not address the absolute accuracy of either radiographic modality; rather, we sought only to determine whether there were diagnostic and clinical implications. Not having a gold standard was the limiting factor in the determination of accuracy. Anatomic dissection would have been necessary to assess the accuracy of either modality; this was not feasible or ethical, since not all teeth were to be accessed surgically or have the bone removed surrounding the impacted anatomic crown to make an accurate assessment.

The maxillary dentitions were segmented by 1 investigator (E.H.), and the 3D views were developed and printed. Inherent problems included the accuracy of segmentation and the selection of angles and views to be presented. In addition, the maximum benefit of CBCT images was limited, since only 2D prints were developed from 3D data, and the clinicians could not manipulate the images to make diagnostic decisions. Future studies should address and compare the accuracy of the radiographic modalities to a gold standard. Clinicians should be allowed to access and manipulate the CBCT scan data to evaluate the true capability of this technology.

CONCLUSIONS

These results suggest that the use of 2D and 3D images of impacted maxillary canines can produce different diagnoses and treatment plans for the same patient. Individual tooth variations affect the determination of the labiopalatal position of an impacted maxillary canine. Three-dimensional volumetric imaging might provide information for improved diagnosis and treatment plans, and ultimately result in more successful treatment outcomes and better care for patients.
REFERENCES


