Three-dimensional decision support system for treatment of canine impaction

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Introduction: This study aimed to develop a 3-dimensional (3D) characterization of the severity of maxillary impacted canines and to test the clinical performance of this characterization as a treatment decision support tool. **Methods:** Cone-beam computed tomography images obtained from 83 patients with 120 impacted maxillary canines were included. Quantitative information on the canine 3D position and qualitative assessment of root damage of adjacent teeth were evaluated. A severity index was constructed on the basis of the quantitative findings. Clinical applicability was tested by comparing clinical diagnosis and treatment planning for conventional records vs the 3D characterization via a 2-part survey. **Results:** The average quantitative assessments of impacted maxillary canine position were 6.4 ± 3.6 mm from the midsagittal plane, 11.6 ± 3.1 mm in height relative to the occlusal plane, 31.5° ± 18° of roll, and 48.8° ± 14.3° of pitch. The severity index ranged from 0-13 with a mean score of 4.5 ± 2.2. Overlap with adjacent teeth was the greatest contributor (33%) to the index. Bicortically impacted canines caused the most severe root damage. Cone-beam computed tomography was preferred for assessing root damage and overall severity, whereas conventional imaging was sufficient for height and angulation assessment. The 3D report was very important or important for evaluating root damage, canine position, overall severity, and overlap. The 3D report changed most of the decisions relating to biomechanics, patient education, and treatment time estimate. The decision of exposure and traction vs extraction was changed 22% of the time after the presentation of the 3D report. **Conclusions:** The overlap with adjacent teeth frequently contributes the most to the severity index. The 3D report provided relevant clinical information regarding the canine position, damage to adjacent teeth, and the severity index, with a profound impact on the decisions of the clinicians regarding biomechanics, patient education, and treatment time estimate. (Am J Orthod Dentofacial Orthop 2023;164:491-504)

Many dental professionals consider the permanent maxillary canines as important functionally, as in canine-guided occlusion, and esthetically.[1] Unfortunately, the permanent maxillary canine is one of the more commonly impacted teeth, second only to third molars.[2] Orthodontists are faced with complex decisions regarding the fate of an impacted canine. The decision requires interdisciplinary planning and care, often involving some combination of the general dentist, pediatric dentist, orthodontist, oral surgeon, dental radiologist, and periodontist. Surgical exposure of the impacted tooth is required, followed by complex orthodontic biomechanics to deliver the tooth into the dental arch, while the patient is

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burdened with additional financial costs and length of treatment.

On clinical examination after the expected eruption timing of the maxillary canines, localized cone-beam computed tomography (CBCT) imaging may be indicated if the canines are not present intraorally.[3] Recent systematic reviews have compared the diagnostic performance of conventional imaging to CBCT and indicated that although CBCT imaging facilitates more consistency in diagnoses and initial management decisions, there is no robust evidence that CBCT should be the first-line imaging method for impacted canines.[4] Furthermore, panoramic radiography may suffice in many patients.[5] Although a previous study concluded that CBCTs provide more precise impacted canine angulation and position, panoramic radiographs could be considered acceptable as there is a lack of evidence regarding the actual impact on patient-oriented outcomes such as treatment time and pain levels.[6]

Controversy persists on whether 3-dimensional (3D) characteristics of impacted canines can potentially provide diagnostic measurements that aid and/or modify the planning of orthodontic traction of the impacted canine. Thus, this study aimed to develop a 3D characterization of the severity of maxillary impacted canines and to test whether the 3D characterization influences clinical decisions and treatment implementation. This comparative effectiveness observational study design aimed to provide evidence of the value of the canine impaction characterization for diagnosing and treatment planning. Specifically, we compare what clinician decisions change with a canine impaction report and whether the implementation differentially affects patient education and decisions related to the therapy of choice, biomechanics of tooth movement and treatment time estimation.

MATERIAL AND METHODS

This investigation involved secondary data analysis of available CBCTs acquired for clinical purposes of patients with maxillary impacted canines. The study was granted Institution Review Board approval (HUM00178973) through the University of Michigan. The sample was collected from the University of Michigan School of Dentistry, University of the Pacific School of Dentistry, Scientific University of the South in Peru and National University of Colombia. Statistical analysis was computed using SPSS software (version 27: IBM, Armonk, NY) for a Poisson log-linear model, intraclass correlation coefficient (ICC), and Cohen's kappa coefficient.

The inclusion criteria were patients with either unilateral or bilateral canine impaction. The exclusion criteria were patients aged <12 years, with craniofacial deformities or syndromes, periapical lesions in the maxillary incisors before orthodontic treatment, history of traction of the impacted canine, and CBCT scans without the anterior nasal spine and maxillary teeth at least until the premolars in their entirety in the field of view.

Table I. Cohort demographics

Sex	*n (%)*	*Age, mean ± standard deviation, y*
Female	50 (60.2)	16.5 ± 5.8
Male	33 (38.8)	16.9 ± 6.2
Cohort	83 (100.0)	16.6 ± 5.9

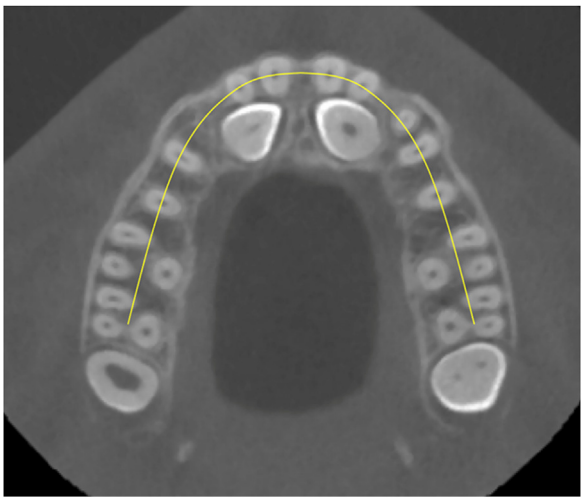


Fig 1. Canine position classification.

Collaborators searched for and collected CBCTs from their internal databases. CBCT files were then shared via uploading to the Health Insurance Portability and Accountability Act-compliant University of Michigan Dropbox. The original digital information and communication in medicine files were deidentified after recording the age and sex of each patient and subsequently converted to neuroimaging informatics technology initiative files using open-source software ITK-Snap (version 3.8; www.itksnap.org). Thirty-seven patients were excluded from the study because they did not meet the inclusion criteria. Of the remaining 83 patients, 120 total canines were available for analysis. Table I summarizes the demographics of the study population. The position of the impacted canine was categorized as either buccal, bicortical, or palatal on the basis of the categorization described by Cuminetti et al[7] (Fig 1). Axial slices were visualized, and the position was determined by the crown position relative to the dental arch. The sample included 32 buccal, 36 bicortical, and 52 palatal canines. Subsequently, 3D image analysis was performed by a single examiner (D.J.K) for each patient.

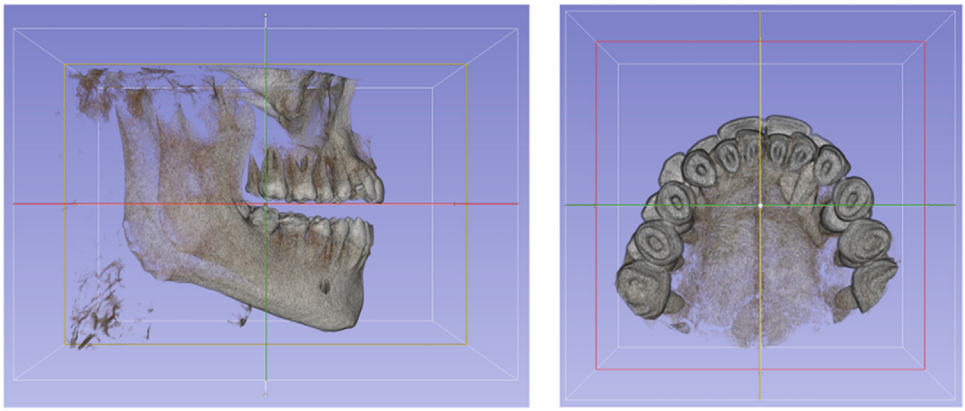


Fig 2. Common scan orientation in 3D Slicer.

Using open-source software 3D Slicer (version 4.11; www.slicer.org), the Transforms tool was used to orient the file on the basis of the following: the midsagittal plane was oriented by visualization of the midpalatal suture, and the axial plane was oriented on the occlusal plane, which was defined by the incisal edges of the central incisors and the functional cusp of the maxillary first molars (Fig 2).

The Segment Editor tool in 3D Slicer was used to highlight bony structures and dentition at a threshold without unwanted scatter.

The anatomic landmarks of interest were prelabeled in ITK-SNAP on the oriented, segmented files. Sagittal, axial and coronal slices of the gray scale scan with superimposed segmentation were visualized for landmark positioning (Fig 3). Table II outlines the landmarks that were labeled.

Using the Model Maker tool in 3Dslicer, surface models (the Visualization Toolkit files) of the segmentations and prelabeled landmarks were generated.

The Visualization Toolkit models of the maxilla and the prelabeled landmarks were simultaneously loaded into 3D Slicer (Fig 4). 3D landmarks were plotted on the prelabeled 3D surface models to quantify measurements using the Quantitative 3D Cephalometrics extension in Slicer (Tables II and III).

Assessment of root resorption to the maxillary central and lateral incisors and first premolar surrounding each impacted canine was completed by visualizing axial, coronal, and sagittal slices of the oriented file in ITK-Snap. The following damage scale was used: 0, none; 1, mild; 2, moderate (less than one-third root); and 3, severe (more than one-third root). A second observer was recruited for the entire sample (M.L.G.), and intraobserver and interobserver reliability was tested.

Cohort means and standard deviations for height, pitch, and roll were used to calculate the contributions to the severity index. Sagittal overlap was reported as 1 of 4 sectors: (1) DU2: distal to the long axis of the lateral incisor (0 points); (2) MU2a: mesial to the long axis of the lateral incisor, less than MU2 average (1 point); (3) MU2b: mesial to the long axis of the lateral incisor, greater than MU2 average (2 points); and (4) MU1: mesial to the long axis of the central incisor (3 points). The severity index is therefore defined as the sum of the deviations from the cohort means for U3 to occlusal plane (height), roll, pitch, and severity sector of overlap. Larger numbers on the scale indicate a more challenging clinical scenario. These data were used to construct 3D diagnostic reports (Fig 5) in step 8. Although root damage is an important finding for the clinician, assigning a contribution to the index would have a confounding effect. Therefore, it was not included as a contributor to the severity index score. For example, more root damage received higher scores and, if added, would result in a higher severity index score; however, the path of the canine has been cleared and would likely lead to canine exposure to replace any hopeless teeth.

Implementation and cross-sectional comparative effectiveness research of the 3D diagnostic report: we tested whether this canine characterization provided more clinically relevant information in diagnosis and treatment planning than the conventional approach. We determined the clinical relevance of the canine impaction reports in terms of different image features and how this information might affect clinical decision-making. Six part-time orthodontic faculty members at the University of Michigan tested the implementation of the 3D diagnostic report. First, 10 patients were selected from the University of Michigan cohort because of the accessibility of conventional records. The patients included 3 patients with bilateral and 7 patients with unilateral maxillary canine impactions. The 10 patients had 13 impacted canines, 6 categorized as palatal, 4 bicortical,

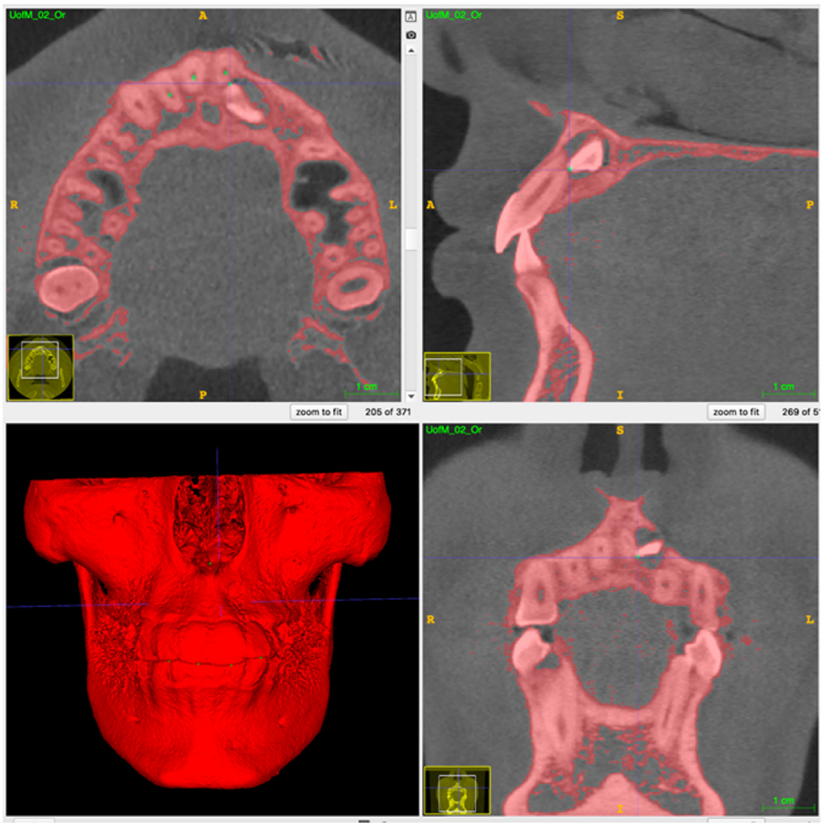


Fig 3. Prelabeling landmarks in ITK-Snap software.

Table II. Description of landmarks

Landmark	*Definition*
IF	Incisive foramen
ANS	Anterior nasal spine
U6	Mesiopalatal cusp tip of the maxillary first molar
U1	The tip of the maxillary central incisor centered along the mesiodistal dimension of the crown
U1A	The apex of the maxillary central incisor. Not the true apex of the root but a point identified approximately two-thirds of the length of the tooth within the canal
U2	The tip of the maxillary lateral incisor centered along the mesiodistal dimension of the crown
U2A	The apex of the maxillary lateral incisor. Not the true apex of the root but a point identified approximately two-thirds of the length of the tooth within the canal
U3	The tip of the maxillary canine
U3A	The apex of the maxillary lateral incisor. Not the true apex of the root, but a point identified approximately two-thirds of the length of the tooth within the canal

and 3 buccal. The patients selected included 2 males and 8 females. The average age was 14 years 2 months, ranging from 12 years 0 months to 16 years 6 months. Faculty were given access to deidentified conventional orthodontic records, including composite photographs, panoramic radiographs, lateral cephalograms (traced with and untraced measurements) and age at the time of records. They were then asked to independently complete a questionnaire regarding each patient (Fig 6). Two weeks after completing their diagnostic questionnaires based on the conventional records, the clinicians received 3D diagnostic reports for the same 10 patients and another survey for each canine (Fig 7).

Statistical analysis

Intraexaminer and interexaminer reliability of qualitative assessment of root resorption was evaluated with the ICC and Cohen's kappa coefficient. Descriptive

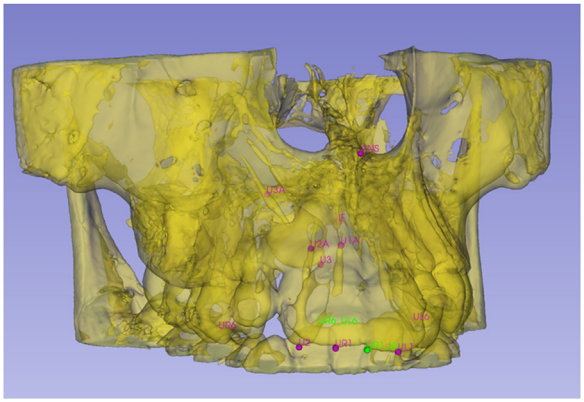


Fig 4. Illustration of fiducial mark placement in Quantitative 3D Cephalometrics.

statistics were used to present the data. In addition, a Poisson log-linear model was used to track changes in the clinical decisions before and after the presentation of the 3D report. Statistical analysis was computed using SPSS software (version 27; IBM, Armonk, NY). Statistical significance was set at $P < 0.05$.

RESULTS

Three out of 120 canines were outliers and not used in the cohort means data analysis because of their extreme deviations in height and angulation. Intraobserver and interobserver reliability were tested for qualitative assessment of root damage. Thirty percent of the sample was repeated for intraobserver reliability, resulting in 97.2% agreement. The entire sample was utilized for interobserver reliability, with 98.3% of patients exact or within 1 category agreement, resulting in an ICC of 0.891. Cohen's kappa coefficient was 0.65, suggesting substantial agreement among observers. The consensus agreement was 355 out of 360 or 98.6%.

Palatal canines possessed the smallest distance to the midsagittal plane (5.0 mm) (Table IV), the shortest average distance to the occlusal plane (10.2 mm), the largest average angulation for roll (34.1°) and pitch (55.7°). Buccal canines had the greatest average distance from both the midsagittal plane (8.5 mm) and occlusal plane (13.2 mm).

Canines with a bicortical position had the highest severity rating of resorption on both the lateral and central incisors (Table V). The lateral incisors were rated very close to moderate on average. Buccal canines had the next highest average severity rating of resorption for the incisors. Regardless of the canine buccal bicortical palatal position, similar amounts of resorption for the first premolars were relatively low. The lateral incisor was the most frequently affected tooth, with 83.8% of lateral incisors expressing at least mild resorption. Maxillary central incisors were affected 40.9% of the time, and maxillary first premolars showed resorption only in 16.4% of patients. The maxillary central incisor was the most varied among the 3 possible impaction positions. Bicortically impacted canines showed some form of resorption to the central incisor 55.6% of the time, whereas buccal and palatal impactions only reported resorption of the central incisor in 34.5% and 34% of patients, respectively.

Table VI illustrates the calculated mean contribution for each of the 4 variables found in the severity index. The average severity for the entire cohort was 4.5, and only the palatally positioned canines had a slightly higher average severity of 4.6. The greatest contributor to the index over the entire cohort was the overlap, accounting for 33% of the severity for the cohort. The categories of height, roll, and pitch contributed equally to make up the remainder of the contribution to the cohort severity. For buccally positioned canines, the height and pitch were the majority contributors. Palatally positioned canines showed the greatest contribution from overlap, with a contribution rate of 43%. The next greatest contributor in the palatal group was the roll, unlike the buccal and bicortical groups, which saw the pitch as the leading angle contributor.

The 3D diagnostic report was shared with the faculty participants 2 weeks after completing the conventional records questionnaire. Overall severity and root damage received the highest number of responses for CBCT imaging as the most appropriate (Table VII). Height received an equal number of responses for both conventional and 3D imaging. Angulation also received many responses for conventional imaging, although 3D imaging still received most clinician responses. The average relevance ratings were lowest for height and angulation, with ratings of 2.69 and 2.93, respectively. The highest relevance ratings were for root damage, with an average of 3.73. The next highest ratings were for the canine position, overall severity, and overlap, all scoring between important and very important.

The second portion of the survey tracked changes in clinical decisions compared with treatment plans using conventional records. Table VIII illustrates the changes in clinician responses and the resulting 95% confidence intervals from the Poisson regression model. The 3D report changed most of the decisions for the categories of biomechanics, patient and parent education, and treatment time estimate. The placement of the traction pad affected nearly half of the decisions made after the clinicians reviewed the 3D information. Overall, 22% of decisions were changed regarding exposure

Table III. Description of measurements

Measurement	*Description*
Maxillary canine to the midsagittal plane (U3 to MSP)	Mediolateral distance in millimeters from the tip of the canine to the midsagittal plane
Maxillary canine to occlusal plane (U3 to OP)	Superior-inferior distance in millimeters from the tip of the canine to the occlusal plane
Pitch	The angle created between the long axis of the canine and the occlusal plane
Roll	The angle created between the long axis of the canine and the midsagittal plane
Overlap	The mediolateral relationship of the tip of the canine relative to the long axes of the lateral and central incisors; distance measured in millimeters and scored DU2 = 0, $MU2_a$ = 1, $MU2_b$ = 2, and MU1 = 3 for severity index
Severity index	The cumulative score of deviations from the cohort normative values for U3 to OP, roll, pitch, and the sector score for overlap

and traction vs extraction after the presentation of the 3D report.

DISCUSSION

The overarching goal of this study is to provide a tool clinicians can use to satisfy one of the orthodontic specialty's challenging treatment goals: the resolution of the maxillary impacted canine. The development and testing of such a tool require first comparison to conventional methods of diagnosis and planning before we implement more modern imaging modalities and tools. This study evaluated information on 3D quantitative and qualitative characteristics that make impacted canines unique, provided clinicians with this new subset of data in a 3D diagnostic report, and compared the clinicians' conventional and 3D diagnosis and treatment planning. It is important to note that the goal of this project is not to replace the valuable interpretation and information provided by specialists in the dental radiology field. Rather, it tests whether information not provided in radiology reports can be useful to clinicians.

The population data of the cohort of this study closely follows that of the reported literature having mostly females compared with females (Table I), unilateral compared with bilateral impactions, and palatally positioned impactions as the majority.[8] To summarize the quantitative 3D data obtained, a severity index was created to give clinicians a concise presentation of the challenges a particular canine may present. Other difficulty indexes have been created and reported in the literature[9,10]; however, this study is the first to exclusively use quantitative data to produce an overall severity rating. Previous studies have adapted the Ericson and Kurol sector method for conventional radiologic assessment of impacted canines.[6,11] This study also adapted Ericson and Kurol's method 3-dimensionally and then summarized it with a newly constructed severity index.

The greatest contributor to the severity index was overlap (Table VI). Björksved et al[6] concluded that when comparing panoramic and CBCT assessments, the sector position of palatally displaced canines was overestimated by radiologists and the angle to the midline. In addition to a high alpha angle and higher vertical position, Grisar et al[12] reported in their systematic review of treatment outcomes of impacted canines that the more mesial sector resulted in less successful interceptive and active treatment results. As such, the importance of the overlap must be considered when computing the overall severity of an impacted canine.

Unlike our deviation-from-the-mean severity point system for pitch, roll, and height, the severity point system for overlap was produced by position relative to the long axes of the maxillary lateral and central incisors. The distance to the midsagittal plane was calculated and considered for use as a contributor to the index. However, the relationship to the maxillary incisors more appropriately dictates the distance a canine must travel to its preferred location. This idea was substantiated when comparing distances in the maxillary canine to the midsagittal plane category to the overlapping category. Some canines shared similar distances to the midsagittal plane; however, their position relative to the long axes of the incisors could be in different sectors. This can be attributed to noncoincident dental and anatomically described skeletal midlines. Moving both the canine and the incisors for orthodontic correction can pose a greater risk of root resorption and increase the treatment time, thus warranting a potentially higher severity index score as the canine increasingly deviates from its normal anatomic position. For all these reasons, our adapted version of Ericson and Kurol's sector method was used for overlap.

The reported quantitative mean for height in this study (Table IV) is similar to other studies.[13-15] Interestingly, Stewart et al[16] reported a statistically significant difference in the duration of treatment between canines with an impaction height of <14 mm vs >14 mm from the occlusal plane. The canines that received

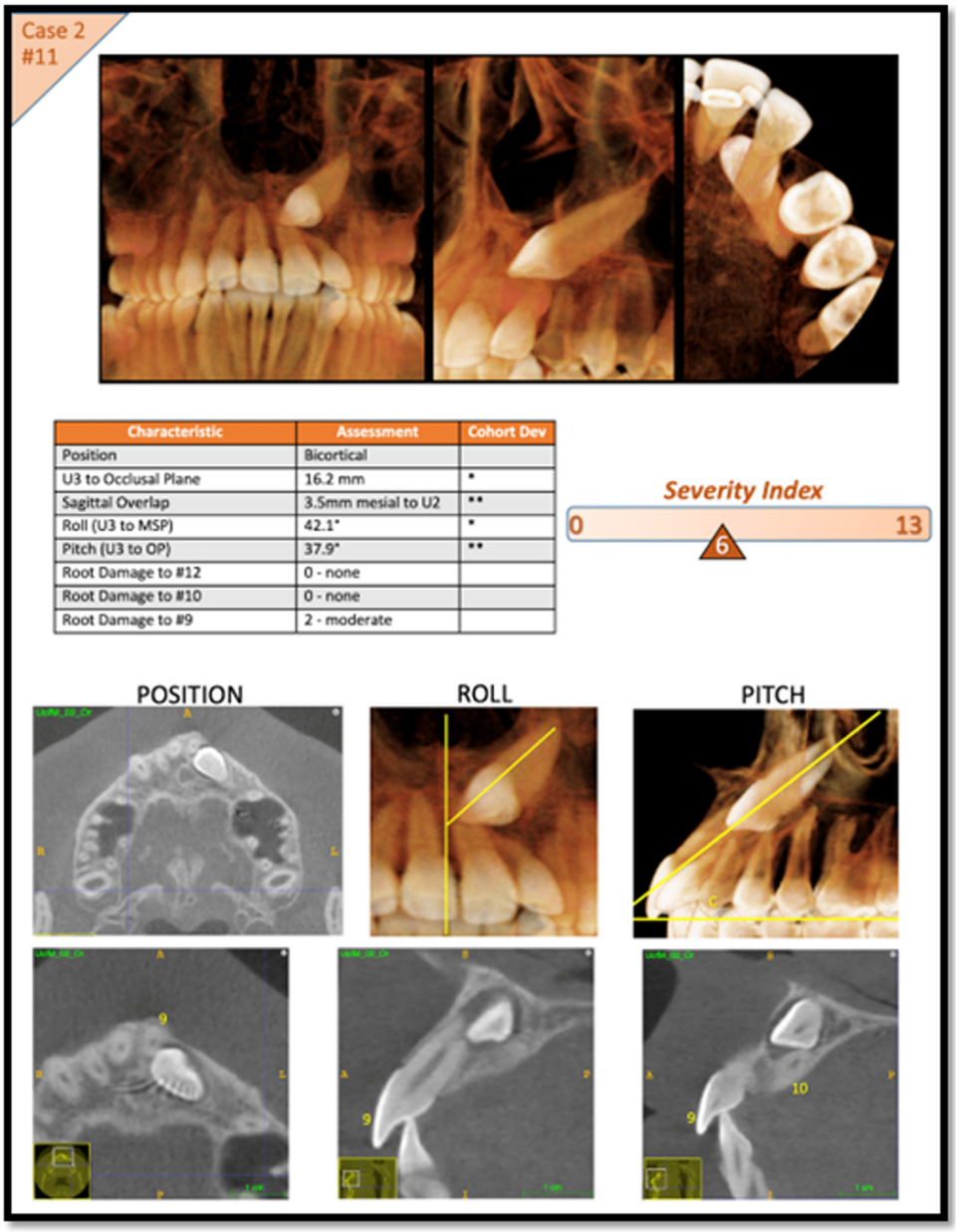
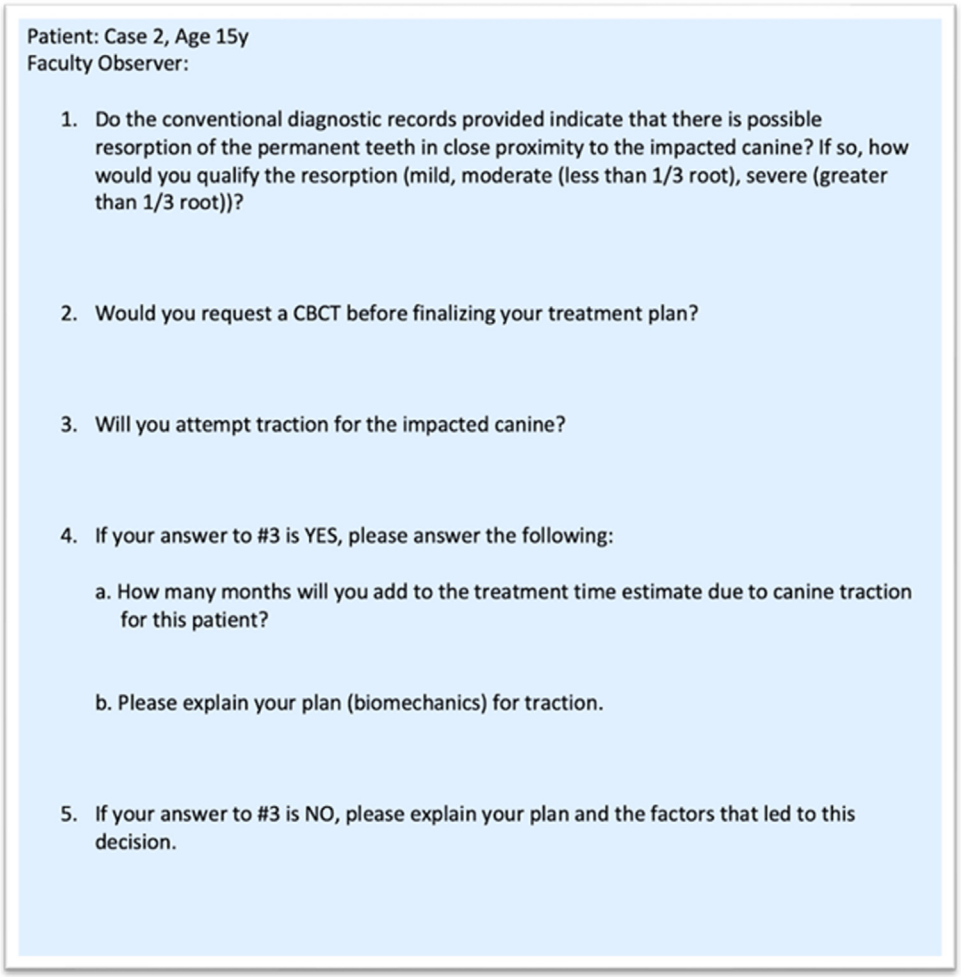


Fig 5. Three-dimensional diagnostic report.

a point toward the severity index in this study had a height greater than the mean of 11.6 ± 3.1 mm for a resultant height of 14.7 mm.

Prior CBCT analysis of root resorption of adjacent teeth indicated that canines with a palatal position caused less severe root resorption when compared with buccal or bicortical positions.[17] In contrast to some other studies which found palatally positioned canines to cause a higher prevalence of root resorption, this study did not find a difference in the prevalence of root resorption as it relates to the buccal bicortical palatal position (Table V).[8,17,18] Ucar et al[19] similarly reported no difference in the prevalence of lateral incisor resorption on the basis of the palatal or labial position of the canine. This study found a higher prevalence of bicortical canines causing resorption to the maxillary central incisor, with the largest root resorption severity rating (Table V).

Resorption of the lateral incisor is frequently reported in studies on impacted maxillary canines. The prevalence of at least mild resorption has a reported range of


Patient: Case 2, Age 15y
Faculty Observer:

1. Do the conventional diagnostic records provided indicate that there is possible resorption of the permanent teeth in close proximity to the impacted canine? If so, how would you qualify the resorption (mild, moderate (less than 1/3 root), severe (greater than 1/3 root))?

2. Would you request a CBCT before finalizing your treatment plan?

3. Will you attempt traction for the impacted canine?

4. If your answer to #3 is YES, please answer the following:

   a. How many months will you add to the treatment time estimate due to canine traction for this patient?

   b. Please explain your plan (biomechanics) for traction.

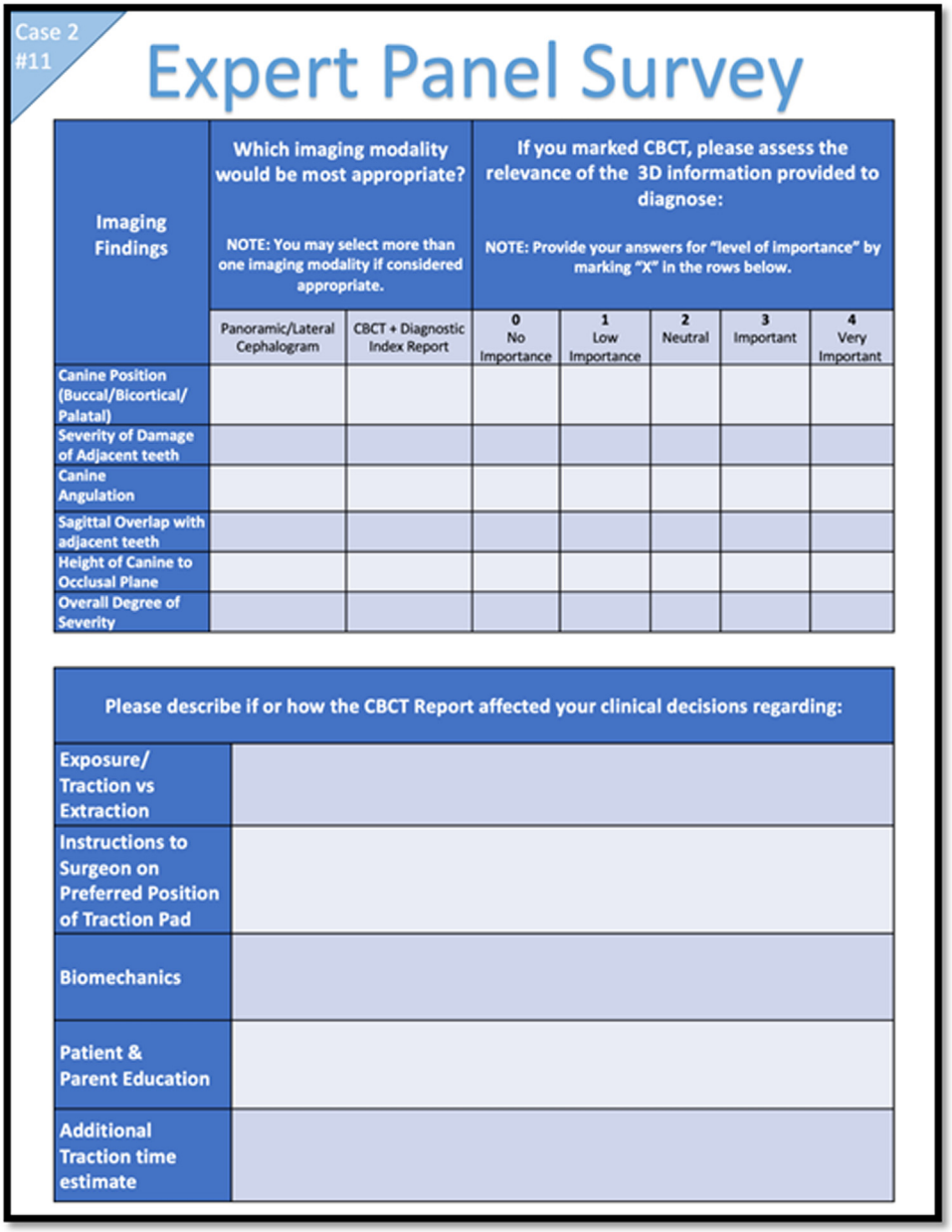
5. If your answer to #3 is NO, please explain your plan and the factors that led to this decision.

Fig 6. Clinician conventional records questionnaire.

18.5%-67.0%.[13,15,20-24] This study had an 84% prevalence of at least mild resorption of the lateral incisors. This can be explained by the method for reporting resorption, as most studies classify slight resorption as "resorption midway to the pulp or more, the pulp lining being unbroken."[22] In contrast, this study rated mild resorption as any surface damage to the root, utilizing a stricter method for classifying mild root resorption.

The potential clinical relevance of the 3D characteristics and severity index was tested by 6 experienced clinicians whose responses to conventional records and 3D records yielded an overall change in responses of 43% (Table VIII), with a 22% change in the decision regarding the extraction of canine in question. This finding is not surprising, considering the CBCT can provide more precise data regarding the condition of the canine and its surrounding teeth.[6] The survey results after the 3D diagnostic report indicate that most changed decisions could be attributed to unforeseen root resorption without the 3D information. The clinicians misdiagnosed root resorption 43% of the time. In the patients in which the decision regarding the canine was changed, root resorption was underreported by the clinicians 77% of the time. Studies comparing conventional panoramic radiographs to CBCT in assessing root resorption in patients of maxillary impacted canines have concluded significant differences in the detection and severity of resorption of surrounding teeth.[21] In the survey after the 3D diagnostic report, the clinicians selected CBCT as the most appropriate imaging modality for diagnosing root resorption at the highest rate among all categories. They also rated the CBCT relevance the highest for root resorption, thus indicating an understanding of the benefits of CBCT to aid in diagnosing and planning these challenging patients.

Assessment of root resorption was not a unique feature of the 3D diagnostic report, nor was it the focus



Case 2
#11

Expert Panel Survey

Imaging Findings	Which imaging modality would be most appropriate? NOTE: You may select more than one imaging modality if considered appropriate.		If you marked CBCT, please assess the relevance of the 3D information provided to diagnose: NOTE: Provide your answers for "level of importance" by marking "X" in the rows below.				
	Panoramic/Lateral Cephalogram	CBCT + Diagnostic Index Report	0 No Importance	1 Low Importance	2 Neutral	3 Important	4 Very Important
Canine Position (Buccal/Bicortical/ Palatal)							
Severity of Damage of Adjacent teeth							
Canine Angulation							
Sagittal Overlap with adjacent teeth							
Height of Canine to Occlusal Plane							
Overall Degree of Severity							

Please describe if or how the CBCT Report affected your clinical decisions regarding:	
Exposure/ Traction vs Extraction	
Instructions to Surgeon on Preferred Position of Traction Pad	
Biomechanics	
Patient & Parent Education	
Additional Traction time estimate	

Fig 7. Clinician 3D diagnostic report survey.

of the new information the study intended to provide. Although root damage may continue to be viewed as the most important information provided by CBCT, the categories of position, overall severity, and overlap all had average relevance ratings between important and very important. Combined with our findings that overlap was the greatest contributor to the severity index for the cohort and the large number of decisions changed in all categories, clinician interest and value in the 3D diagnostic report may rise. Although CBCT is the preferred method of impaction evaluation by the authors of this study, it is understood that access to CBCT imaging, patient finances, and provider preference all play a role in obtaining this diagnostic information.

Interestingly, the CBCT relevance ratings for height and angulation (pitch and roll), which account for 3 out of the 4 contributors to the severity index, received the lowest average ratings from the panel, which is in agreement with the findings of Björksved et al.[6] These 2 categories also received the highest number of

Table IV. Summary of 3D measurements

Measurements	*Buccal (n = 29)*	*Bicortical (n = 36)*	*Palatal (n = 52)*	*Cohort*
Maxillary canine to the midsagittal plane				
Mean ± SD	8.5 ± 3.7	6.8 ± 3.8	5.0 ± 2.7	6.4 ± 3.6
Range	1.6-19.7	0.7-15.9	0.5-11.3	0.5-19.7
Maxillary canine to occlusal plane				
Mean ± SD	13.2 ± 3.4	12.3 ± 2.8	10.2 ± 2.5	11.6 ± 3.1
Range	7.1-19.4	6.7-20.5	5.4-14.9	5.4-20.5
Overlap				
DU2 (n = 29)	2.6 ± 2.4	2.2 ± 1.5	0.6 ± 0.4	2.2 ± 1.9
MU2 (n = 57)	2.2 ± 1.7	3.4 ± 1.6	3.4 ± 1.7	3.1 ± 1.7
MU1 (n = 31)	1.1 ± 0.3	1.6 ± 1.5	1.8 ± 1.2	1.7 ± 1.3
Roll				
Mean ± SD	26.9 ± 17.5	30.9 ± 21.2	34.1 ± 15.9	31.5 ± 18.0
Range	2.1-63.6	2.4-75.2	1.7-73.7	1.7-73.7
Pitch				
Mean ± SD	39.9 ± 11.5	46.1 ± 16.0	55.7 ± 10.9	48.8 ± 14.3
Range	18.8-68	5.8-76.2	23.6-78.4	5.8-78.4
Severity index				
Mean ± SD	4.5 ± 2.1	4.5 ± 2.7	4.6 ± 1.9	4.5 ± 2.2
Range	1-10	0-10	0-10	0-13

SD, standard deviation.

Table V. Consensus root damage qualitative assessment summary

	Impacted canine position			
Adjacent maxillary tooth	*Buccal*	*Bicortical*	*Palatal*	*Cohort*
First premolar (U4)				
Qualitative mean ± SD	0.2 ± 0.4	0.2 ± 0.5	0.2 ± 0.4	0.2 ± 0.5
Consensus qualitative assessment, n				
None	23	30	44	97
Mild	5	4	7	16
Moderate	0	2	1	3
Severe	0	0	0	0
Percentage with resorption	17.9	16.7	15.4	16.4
Lateral incisor (U2)				
Qualitative mean ± SD	1.5 ± 1.1	1.8 ± 1.1	1.0 ± 0.7	1.4 ± 1.0
Consensus qualitative assessment, n				
None	5	5	8	18
Mild	9	11	36	56
Moderate	6	5	4	15
Severe	6	13	3	22
Percentage with resorption	80.1	85.3	84.3	83.8
Central incisor (U1)				
Qualitative mean ± SD	0.7 ± 1.1	1.2 ± 1.3	0.5 ± 0.9	0.8 ± 1.1
Consensus qualitative assessment, n				
None	19	16	33	68
Mild	3	7	12	22
Moderate	4	2	1	7
Severe	3	11	4	18
Percentage with resorption	34.5	55.6	34	40.9

SD, standard deviation.

clinician responses for conventional imaging. This may be attributed to each clinician's experience using traditional means of diagnosis during their careers.

The design of a 2-part survey of 6 calibrated clinician experts in this study was performed as a cross-sectional observational comparative effectiveness research to

Table VI. Contribution to the severity index

Variables	*Overlap*	*Height*	*Roll*	*Pitch*	*Severity index*
Buccal (n = 29)	0.9 ± 1.0	1.4 ± 0.8	0.9 ± 0.6	1.3 ± 0.7	4.5 ± 2.1
Bicortical (n = 36)	1.3 ± 1.2	1.0 ± 0.6	1.0 ± 0.9	1.1 ± 0.9	4.5 ± 2.7
Palatal (n = 52)	2.0 ± 1.0	0.8 ± 0.5	1.2 ± 0.6	0.7 ± 0.5	4.6 ± 1.9
Cohort	1.5 ± 1.1	1.0 ± 0.7	1.0 ± 0.7	1.0 ± 0.7	4.5 ± 2.2

Note. Variables are presented as mean ± standard deviation.

Table VII. Summarized responses to the clinician survey

Clinical diagnosis or decision	*Clinician choices*	*Clinician responses*	*Clinician percentage*	*3D report relevance*
Which imaging modality would be most appropriate to diagnose impacted canines?[†]				
Position	2D	15	25.00	NA
	3D	52	86.67	3.63
Root Damage of Adjacent Teeth	2D	5	8.33	NA
	3D	59	98.33	3.73
Angulation	2D	34	56.67	NA
	3D	50	83.33	2.93
Overlap with Adjacent Teeth	2D	9	15.00	NA
	3D	56	93.33	3.34
Height	2D	42	70.00	NA
	3D	42	70.00	2.69
Severity Index	2D	8	13.33	NA
	3D	59	98.33	3.57
Did the 3D diagnostic report change the clinical decision regarding:				
Exposure and traction vs extraction	No change	47	78.33	
	Change	13	21.67	
Placement of traction pad	No change	36	60.00	
	Change	24	40.00	
Biomechanics	No change	23	38.33	
	Change	37	61.67	
Patient and parent education	No change	11	19.33	
	Change	49	81.67	
Additional treatment time estimate	No change	29	48.33	
	Change	31	51.67	

NA, not available.
[†]Respondents could select >1 modality.

determine the effects of the canine impaction characterization report on diagnosis and treatment planning.[25] One of the challenges in applying clinical decision support tools in diagnosis, classification and treatment planning is the lack of evidence of benefits and risks of the tool compared with the conventional records. Therefore, it is crucial to apply effective comparative research to understand the following: (1) compared with the conventional approach, whether our canine characterization provides more clinically relevant information in diagnosis and treatment planning; (2) what is the level of the clinical relevance of the canine impaction reports in terms of different image features; and (3) how this information might affect the clinical decision-making. The results of the clinician survey indicate the effectiveness of the proposed canine impaction characterization and point to the need for future studies to automate these assessments, taking advantage of recent advancements in artificial intelligence technologies. Figure 8 presents a step-by-step decision workflow to facilitate the readers understanding and encourage clinicians to attempt to use it when questions on canine impactions arise.

As a cross-sectional study, one of the inherent limitations is the collection of data at a snapshot in time. Complete validation of the severity index should include a comparison to treatment outcomes, including treatment duration, traction success, additional tooth resorption, and the periodontal health of the canine. In addition, a

Table VIII. Summarized responses to clinical decisions survey

	Did the CBCT report change the clinical decision regarding:										
	Exposure and traction vs extraction		*Placement of traction pad*		*Biomechanics*		*Patient and Parent Education*		*Additional treatment time estimate*		*Percentage of changed responses per patient*
Variables	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	
Patient											
01	0	6	2	4	2	4	3	3	0	6	19
02	1	5	4	2	5	1	6	0	2	4	50
03	1	5	3	3	3	3	3	3	2	4	33
04	1	5	2	4	3	3	6	0	4	2	44
05	2	4	4	2	6	0	6	0	6	0	67
06	4	2	4	2	5	1	6	0	5	1	67
07	0	6	1	5	3	3	6	0	2	4	33
08	3	3	4	2	6	0	6	0	6	0	69
09	1	5	0	6	2	4	3	3	3	3	25
10	0	6	0	6	2	4	4	2	1	5	19
Total responses	13	47	24	36	37	23	49	11	31	29	43
Clinician % change	21.7		40.0		61.7		81.7		51.7		
95% confidence interval	12.6-37.3		26.8-59.7		44.7-85.1		61.7-100		36.3-73.5		

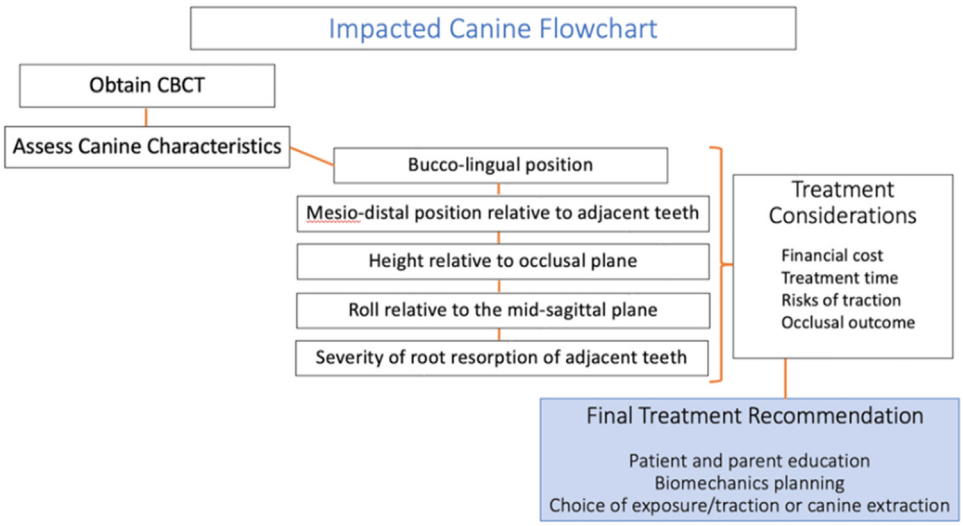


Fig 8. Flowchart of the clinician decision-making process

relatively small sample of patients was used to test clinical applicability, and all clinicians were from the same clinical center. Testing of the index over several clinical sites is preferred for implementation. Research in progress aims to automate many of the processes performed in this study. In future extensions of these research efforts, machine learning may provide automatic segmentation, landmark identification, and quantitative assessment to provide a subsequent diagnostic output readily available for the clinician. Ultimately, this data may not only help clinicians resolve difficult treatment decisions but, more importantly, help our patients.[8]

CONCLUSIONS

Quantitative assessments of the canine position, overlap with adjacent teeth, angulation and height were used to determine a severity index of canine impaction. The overlap with adjacent teeth frequently contributes the most to the severity index. Only buccally positioned canines had height as the lead contributor to the severity index. Bicortically impacted canines were found to cause the most severe root damage, and palatally impacted canines caused the least severity of the damage.

Clinicians prefer CBCT to conventional imaging modalities to diagnose and plan impacted canines. The 3D diagnostic report did have a profound impact on the decisions of clinicians when compared with conventional planning.

AUTHOR CREDIT STATEMENT

Dylan J. Keener contributed to methodology, investigation, data curation, formal analysis, original draft preparation; Antonio Carlos de Oliveira Ruellas contributed to conceptualization, methodology, supervision, and manuscript review and editing; Aron Aliaga-Del Castillo contributed to resources, conceptualization, and manuscript review and editing; Luis Ernesto Arriola-Guillén contributed to data curation and manuscript review and editing; Jonas Bianchi contributed to resources, data curation, and manuscript review and editing; Heesoo Oh contributed to resources, data curation, and manuscript review and editing; Marcela Lima Gurgel contributed to investigation, validation, visualization, and manuscript review and editing; Erika Benavides contributed to resources and manuscript review and editing; Fabiana Soki contributed to resources and manuscript review and editing; Yalil Augusto Rodríguez-Cárdenas contributed to resources, data curation, and manuscript review and editing; Gustavo Armando Ruíz-Mora contributed to resources, data curation, and manuscript review and editing; Mary Barkley contributed to investigation and manuscript review and editing; Thomas Gebeck, Jr, contributed to investigation and manuscript review and editing; Eric Hannapel contributed to investigation and manuscript review and editing; Laurie McNamara McClatchey contributed to investigation and manuscript review and editing; Maria Pinzon contributed to investigation and manuscript review and editing; Christopher Roberts contributed to investigation and manuscript review and editing; and Lucia Cevidanes contributed to conceptualization, methodology, formal analysis, supervision, and manuscript review and editing.

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