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Review

Orthodontic Localization of Impacted Canines: Review of the Cutting-edge Evidence in Diagnosis and Treatment Planning Based on 3D CBCT Images

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Main Points

- A thorough clinical and radiographic assessment is a prerequisite for a successful treatment of impacted canines.
- 3D imaging such as cone-beam computed tomography provides more detailed information regarding the location of impacted canines and more precise estimation of the space conditions in the arch.
- Accurate localization of the three-dimensional position of impacted canines is the key in planning the most efficient biomechanical approach for their traction.

ABSTRACT

A thorough clinical and radiographical assessment of an impacted maxillary canine's location forms the basis for proper diagnosis and successful treatment outcomes. Implementing a correct biomechanical approach for directing force application primarily relies on its precise localization. Poor biomechanical planning can resorb the roots of adjacent teeth and result in poor periodontal outcomes of the canine that has been disimpacted. Furthermore, treatment success and time strongly rely on an accurate assessment of the severity of impaction, which depends on its 3D spatial location. The evolution of cone-beam computed tomography (CBCT) radiographs provides more detailed information regarding the location of the impacted canines. In addition, the literature has shown that CBCT imaging has enhanced the quality of diagnosis and treatment planning by obtaining a more precise localization of impacted canines. This review article highlights current evidence regarding comprehensive evaluation of three-dimensional orientations of impacted canines on CBCT images for precise diagnosis and treatment planning.

Keywords: Impacted canines, 3D localization, CBCT

INTRODUCTION

When an impacted maxillary canine is present, it often presents challenges in diagnosis, localization, and management. Mandibular canine impaction is less than half as likely to occur than maxillary canine impaction, and of the patients who belong to the latter group, 8% have bilateral impaction.[1] About two-thirds of the impactions are located palatally, while one-third are set buccally.[2,3] Therefore, the literature is abundant in studies that investigated maxillary impacted canines. Buccal canine impaction is considered a result of crowding. Jacoby had evidence to support that only 17% of buccal impactions have adequate eruption space, compared to 85% for palatal impactions. Nonetheless, with sufficient space and time, buccally impacted canines will typically erupt.[4] Two major theories were proposed to be associated with palatally impacted maxillary canines. The

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guidance theory, which mentions that canine eruption depends on the lateral incisor's root, and deviation in the development of the latter can hinder canine eruption.[4] In contrast, Becker[4,5] suggested the genetic theory, which supports a genetic etiology for palatally impacted canines and proposes a potential link to related anomalies, including absent or irregular lateral incisors.

Treatment of impacted canines generally involves surgical exposure and subsequent orthodontic bonding to guide it into the proper position in the arch.[6] Considerable debate surrounds the choice of the exposure technique for ectopic canines. Those advocating the closed eruption approach cite benefits in terms of patient comfort and long-term periodontal health. On the other hand, clinicians who support the excision of the overlying mucosa and spontaneous eruption of the canine mention advantages in terms of fewer repeated operations.[7] However, the most common complications that pose a challenge during treatment include bone loss, root resorption, and compromised periodontal outcomes of the impacted canine and surrounding teeth.[8] Therefore, accurate assessment of the position of the impacted maxillary canine is an essential aid in determining the severity of impaction, difficulty in management, adequate surgical exposure procedure, and overall prognosis of treatment.[9,10]

Localization of impacted maxillary canines relies on both clinical and radiographic evaluation.[2] For a practitioner to achieve proper diagnosis and successful treatment outcomes, it is imperative to accurately assess the exact location of the impacted tooth and determine its severity to define the treatment duration and complexity. Clinical evaluation alone is not conclusive of an accurate diagnosis or localization, especially that impacted canines vary greatly in their inclination and location, which might contribute to cystic degeneration or root resorption for neighboring teeth.[11] Therefore, it is essential for the clinical evaluation to be supplemented by radiographic analysis.

Numerous (2D) radiographic images have been used to evaluate the position of impacted canines, including panoramic, periapical, occlusal, and lateral cephalometric views.[12] However, these traditional radiographic images are (2D) representations, and the canine's position can be confounded with distortion and overlapping structures. Approximately 80% of clinicians should use two or more supplemental traditional radiographs to localize an impacted tooth.[13] Therefore, cone-beam computed tomography (CBCT) and CT were introduced as an aid in diagnosis.[14] The introduction of CBCT marks a profound advancement in dental radiology. This innovation in [three-dimensional (3D)] imaging appears to offer the potential for improved diagnosis in a wide range of clinical applications, and radiation is usually at lower doses compared to medical CT.[15] Additionally, the literature has shown that CBCT imaging has enhanced the quality of diagnosis and treatment planning by obtaining a more precise localization of impacted canines.[16] This review article highlights current evidence regarding the comprehensive evaluation of 3D orientations of impacted canines on CBCT images, for precise clinical diagnosis, treatment planning, and implementation of a proper biomechanical approach for traction based on their 3D location.

3D Localization of Impacted Maxillary Canines using CBCT versus 2D Conventional Methods

The diagnostic value of (3D) images lies in their ability to precisely locate impacted canines in three planes of space. Furthermore, the choice of the surgical orthodontic management and determination of the direction of traction relies primarily on the location of the impacted tooth relative to adjacent structures and its depth and inclination in the jaw.[17] Limitations encountered with the use of conventional radiography, such as the superimposition of adjacent structures, magnification, distortions, and the need for more than one radiographic image to accurately localize an impacted canine, hinder their diagnostic ability to precisely localize impacted canines.[18] CT scans were used initially as an alternative. Even though they offered more efficient information than conventional radiographs, limitations related to their radiation dose, cost, risk/benefit, access, and expertise in their evaluation, restricted their use in localizing impacted teeth.[19] CBCT images require lower radiation doses compared with CT scans.[15] They also appear to accurately delineate the spatial location of impacted canines and their surrounding structures, hence ensuring optimal orthodontic surgical management. Walker et al.[16] were among the first to use images from NewTom QR-DVT 9000 (QR Sri, Verona, Italy) to depict the positioning of impacted canines. They showed that the implementation of CBCT radiography-improved detection rates of root resorption adjacent to the impaction up to 66.7%.

Studies that compared the diagnostic efficacy of the two imaging modalities, conventional radiographs vs. CBCT scans, in localizing the impacted maxillary canines have illustrated the superiority of the latter. Haney et al.[20], used a questionnaire to compare the differences in diagnosis and treatment planning of impacted canines between CBCT images and various conventional radiographic modalities (panoramic, occlusal, and periapical radiographs). They concluded that the use of these two image modalities produced different diagnoses and treatment plans for the same patient. In another questionnaire-based study, respondents found that the 2D conventional and 3D CBCT images had different diagnostic capabilities with regard to localize impacted canines. In addition, observers had greater agreement when using CBCT images for variables related to impacted maxillary canines.[21] In a subsequent CBCT study, a model was established to predict canine impaction. The factors included in this model were crown position of the canine, angulation of the canine with respect to the lateral incisor, and cusp tip of the canine in relation to the plane of occlusion. They determined that reliability was high when CBCT imaging was used to predict canine impaction.[22]

Multiple studies have compared the radiation doses between 2D and 3D radiological examinations. The average effective dose for panoramic and lateral cephalometric X-rays were around 22.0 μSv and 4.5 μSv, respectively. Comparatively, the effective dose for a CBCT examination ranged between 61 and

134 μSv.[23] For that reason, the American Academy of Oral and Maxillofacial Radiology (AAOMR) recommend CBCTs only for certain cases where conventional 2D methods cannot provide enough diagnostic information, such as cleft cases, impacted teeth, and orthognathic surgery planning.[24]

In a recent systematic review, Eslami et al.[25] reviewed observational, experimental, and diagnostic accuracy studies that compared the efficacy of CBCT images to conventional radiography in localizing maxillary impacted canines. They illustrated the improved accuracy of CBCT scans in localizing impacted canines. However, they mentioned that evidence is weak to support their use as a first-line imaging method for evaluating canine impaction. However, they can be indicated when conventional radiography does not provide sufficient information. Therefore, the supporting evidence seems to indicate that the CBCT system is a reliable method for detecting impacted canines, and the current literature illustrates the supremacy of CBCT images over other conventional radiographic techniques as an aid for the diagnosis and visualization of impacted maxillary canines and adjacent structures.[26]

Use of CBCT Images in Assessing the Location and Severity of Impacted Maxillary Canines

Initial attempts to localize an impacted canine and determine the degree of its severity were based on analyzing (2D) radiographs. Among the pioneers in the field, Ericson and Kurol[2] classified the position of impacted canines in both frontal and transverse sections using orthopanthograms and axial vertex views. They used an angle (α) to denote the relationship between the long axis of the canine and the mid sagittal plane of a panoramic radiograph. Frontal and transverse planes were divided into five sectors, and the medial position of the crown in relation to these sectors was evaluated. The perpendicular distance (d) was measured from the impacted cuspid's tip to the occlusal plane (Figure 1A). They concluded that the probability of lateral incisor root resorption increases by 50% if the canine cusp tip is closer to the midline (within sectors 4 or 5) and the angle exceeds 25°. Furthermore, the duration of treatment was longer if the canine was in sector 3 and shorter for impaction in sector 1 (further away from the midline).[2]

Ericson and Kurol's[2] sector classification was redefined by Lindauer et al.[27]. Who located the canine's cusp tip relative to its proximal lateral incisor. He determined the likelihood of impaction using the sector classification. Sector I was classified as a region distal to the distal border of the lateral incisor. Sector II is the distal half of the lateral incisor when bisected through its long axis. Sector III denoted the mesial half of the lateral incisor when bisected through its long axis. Sector IV represents the area mesial to the mesial border of the lateral incisor. With this approach, it is estimated that 78% of unerupted canines located in sectors II, III, and IV would be impacted. Warford et al.[28], found 82% of impacted canines were in sectors II, III, and IV. They suggested that the sector approach had stronger reliability than angulation and provided canine impaction risk assessment from sectors and angles (Table 1).

In another attempt, Power and Short[29] investigated the success of the eruption of palatally impacted canines after removing their deciduous predecessor. Panoramic radiographs were used to evaluate the severity of impaction. They recorded the following: canine-incisor overlap, its angulation relative to the midline, eruptive level relative to the nearest incisor root, and the vertical height from the canine tip to a horizontal line drawn tangent to the central incisal edges. The authors concluded that the treatment outcome depends on these radiographic variables, of which canine-incisor overlap had the most significant impact (Figure 1B).[29]

On the other hand, Fleming et al.[30] used panoramic radiographs to extrapolate the appropriate duration for orthodontic alignment. They assessed radiographic variables related to the vertical displacement of the impacted canine, long axis angulation, proximity of the canine cusp tip to the midline and proximal incisors, and the anteroposterior apex location. The location of the impacted canine with respect to the midline influenced the treatment time the most. Furthermore, the treatment time could not be associated with the anteroposterior position of the apex, mesiodistal location, or long axis-midline angulation (Figure 1C).[30]

Eventually, with the introduction of CBCT scans, profound comprehension of impacted canines and an efficient biomechanical approach for their management became feasible. Kau et al.[31] were the first to suggest an index (KPG) that used information provided by CBCT imaging to evaluate the complexity in treating impacted canines. Based on the canine's anatomical location, its cusp tip and root tip were scored (0-5) in three dimensions (X,Y,Z). The sum of these scores in two views (frontal and axial) dictated the anticipated difficulty of treatment.[31] Despite the good level of agreement between the clinician's perception and the KPG index score for the difficulty of impaction,[32] reliability in using this index varied between different software used for the analysis.[33] In addition, this index did not take into consideration the sagittal view and did not evaluate the angulation of the longitudinal axis of the impacted canine relative to a standard reference plane (Figure 2).

Similarly, Liu et al.[34] also attempted to three-dimensionally localize impacted canines and assess the amount of adjacent incisors' root resorption. Angular and linear measurements were undertaken in axial and paraxial sections. Their classification

Table 1. Warford et al.[28] classification of impacted canines (probability of canine impaction based on sector and angle classification)

Angle (degrees) classification	Sector classification			
	I	II	III	IV
40-54°	0.11	0.53	0.91	0.99
55-69°	0.08	0.43	0.87	0.98
70-84°	0.05	0.33	0.81	0.98
85-99°	0.04	0.25	0.75	0.96
Angle not considered	0.06	0.38	0.87	0.99

was descriptive and not related to standardized measurements. They found that the displacement of impacted maxillary canines is widely variable and is usually associated with the resorption of proximal incisors.[34] More recently, Zeno and Ghafari[35] hypothesized that the severity of impaction and treatment required can be specified based on the location of the palatally impacted canine in relation to its expected final position in the dental arch. Their objective was to evaluate the impaction severity by three-dimensionally assessing the position of palatally impacted canines. The angulation of impacted canines was measured relative to its final expected position, midline, and palatal plane. Their measurements also included cusp tip to apex length. The highest severity of impaction was seen when the canine tip point was medial, and the apex was posterior. They noted that further research is needed to take other variables, such as treatment duration, into account when performing severity scoring (Figure 3).[35]

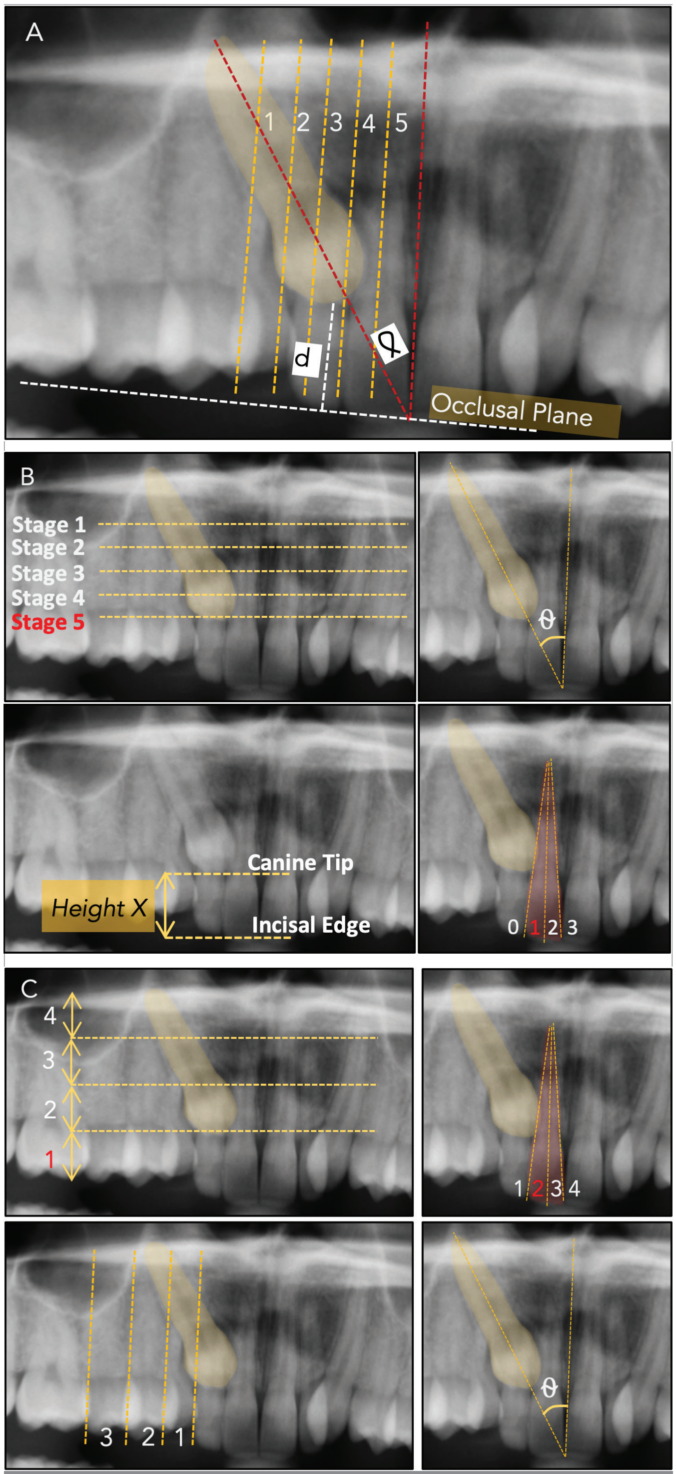

Figure 1A-C. Initial attempts to assess the location of impacted canines. A) Ericson and Kurol,[2] **B)** Power and Short,[29] **C)** Fleming et al.[30].

Despite the previous attempts, a comprehensive standardized and objective analysis of (3D) locations and orientations of impacted canines was lacking.[14,16,17,36] The previous classifications were not based on a standardized vertical, horizontal, and angular analysis of impaction. They lacked an objective scoring system to assess the severity of impaction. Severity assessment will help determine the treatment duration and mechanics necessary to resolve the impaction. Furthermore, it will assist in choosing the best surgical exposure technique to resolve the impaction.

Recently, Ross et al.[37] developed a comprehensive standardized index that quantified the (3D) location of impacted canines in the three planes of space (sagittal, coronal and axial). Specifically, it included angular measurements of the long axis of the canine relative to adjacent teeth. They also assessed the linear distances to standardized reference planes in the sagittal, coronal, and axial views using CBCT scans. This index was adopted to evaluate the severity of the impaction (mild, moderate, or severe) based on the impacted canine's (3D) location. Scores were given for each category of severity. A nomenclature that indicates the location of the canine was suggested to enhance the communication between the clinicians. In their study, they concluded that the majority of the severely impacted canines had their crowns buccal in relation to the maxillary arch, closer to the occlusal plane and mesial to the distal border of the central incisor with more than 45° buccal inclination and an exaggerated mesial tip. They concluded that the sagittal angle of the impacted canine had a significant effect on the severity of impaction (Figure 4).[37]

Clinical Significance of the Radiographic Predictors and Precision of Locating an Impacted Canine Using 3D Radiographs

Variations in the spatial location of the impacted canines define the complexity of the impaction and help assess the treatment duration. Additionally, 3D radiographs serve as an aid to the clinician in the decision-making process regarding management and prognosis (Figure 5).[35,38] Several factors were reported in the literature and can be associated with the duration of traction of an impacted canine, among which are: number of impaction, accurate pretreatment radiographic evaluation using (2D) radiographs, and indices computed, and proposed in the literature from (2D) radiographs and more recently (CBCT) images.[2,5,11,35,38]

Previous studies in grading the severity of impacted canines using (2D) radiographs illustrated four major radiographic

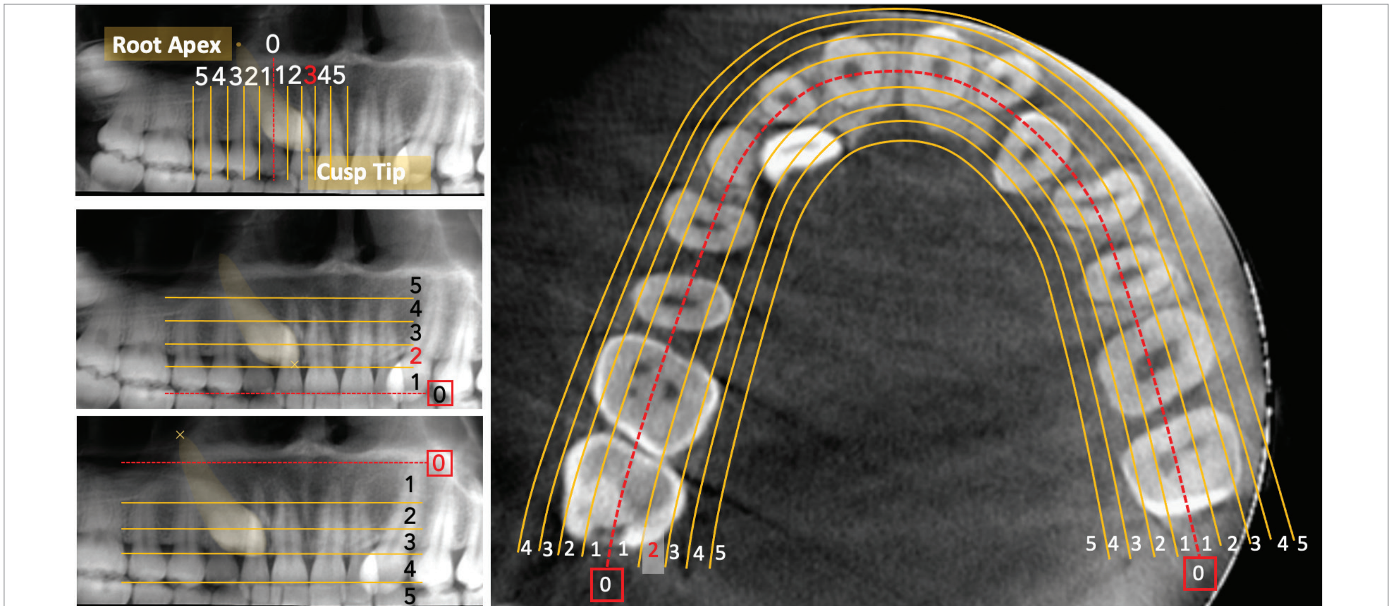

Figure 2. Clinical example of the Kau index

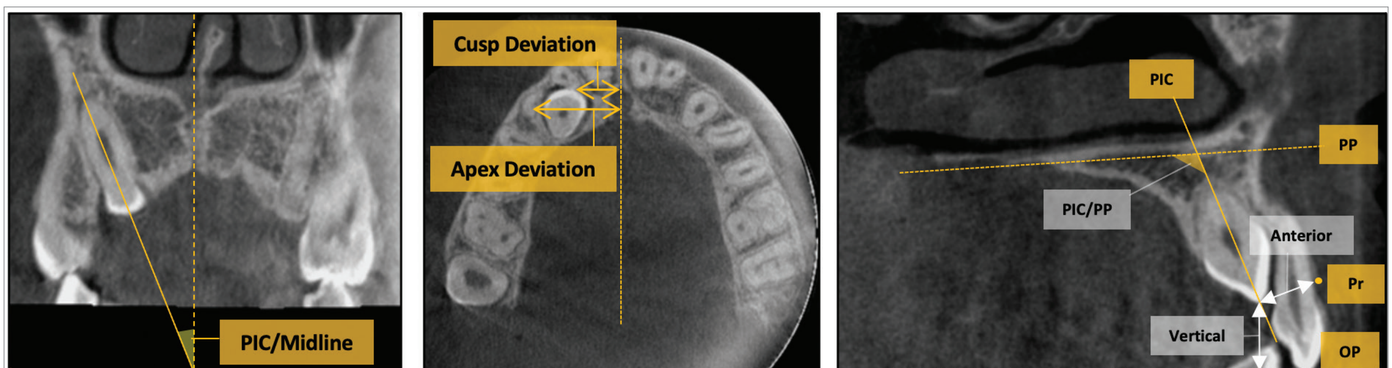

Figure 3. Clinical example of a measurement from Zeno and Ghafari[35]

predictors that showed some evidence correlated with the complexity of managing an impacted canine. The predictors included overlap with the proximal incisor, long axis-midline angulation, sagittal position of the apex, and vertical displacement of the crown tip.[39]

Regarding vertical displacement of the canine tip in association with severity found that when the impacted canine crown was at a distance of less than 14 mm from the occlusal plane, treatment time averaged 23.8 months; a distance of more than 14 mm required an average treatment time of 31.1 months.[39] Historically, Ericson and Kurol[2,40] were the first to illustrate the significance of this vertical distance as a predictive factor during treatment. This distance also dictated the outcomes of their suggested interceptive treatment i.e. extraction of the deciduous canine and maintaining the space in the maxillary dental arch.[41,42] On the other hand, Fleming et al.[43] reported that vertical height did not influence the treatment duration.

The horizontal mesiodistal location of the canine is a predictive factor for its severity of impaction and duration of traction. Fleming et al.[30] demonstrated that canine crown location in relation to proximal teeth and midline is associated with treatment duration. Alternately, Zuccati et al.[38] indicated a strong direct correlation between the horizontal mesiodistal location of the canine and treatment duration.

Moreover, the influence of impacted canine angulation on the midsagittal plane in panoramic radiographs on treatment duration has been previously studied.[39,43] Due to the limitations of the (2D) radiographs, assessment of the influence of sagittal angle on treatment complexity and duration was not feasible. The sagittal angle is critical in evaluating the severity of the impacted canine. The severity of this angle indicates a more challenging path of eruption and reflects the difficulty in moving the root buccally during orthodontic treatment.[44] A greater mesio-distal tip, will increase the risk of damaging adjacent roots during canine traction. Consequently, the more severe these angles, the greater the need for the canine to be uprighted and distanced from the incisors' roots; once uprighted can be pulled toward the arch. Therefore, uprighting with orthodontic traction on the opposite side would be required.[42] Additionally, the torque correction for the roots will increase the treatment duration to finally be able to engage the canine into a rectangular SS archwire. And even if the canine was close to the occlusal plane, the non-linear biomechanics of traction based on the severity of the sagittal and coronal angulation play a crucial role in predicting the severity and traction duration.[10] Hence, the clinical significance of CBCT scans in evaluating both angles.

The controversy in the literature regarding the influence of some of the above-mentioned radiographic predictors on the severity of impaction and duration of treatment can be

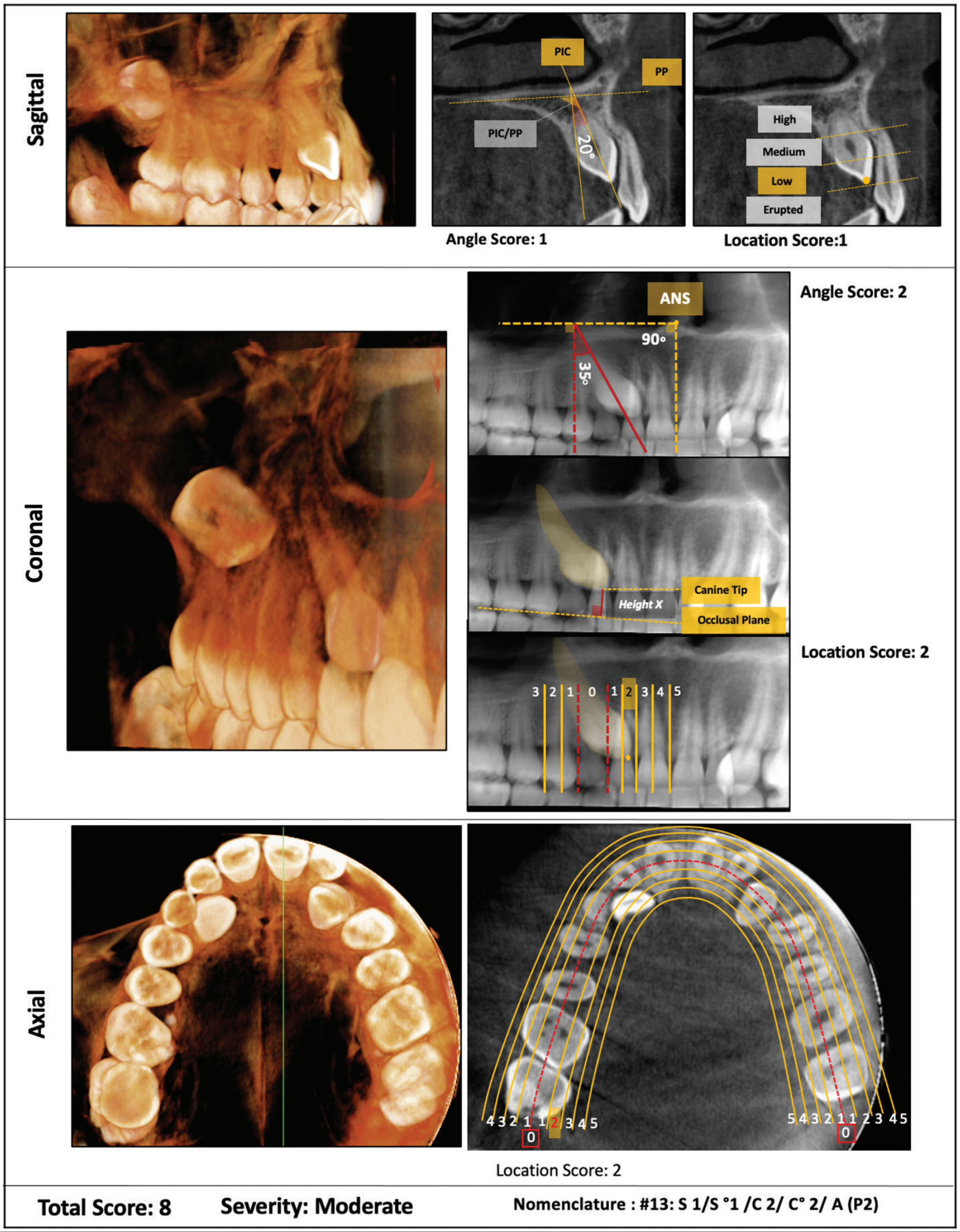

Figure 4. Clinical example for the application of the current index to evaluate the severity of impaction

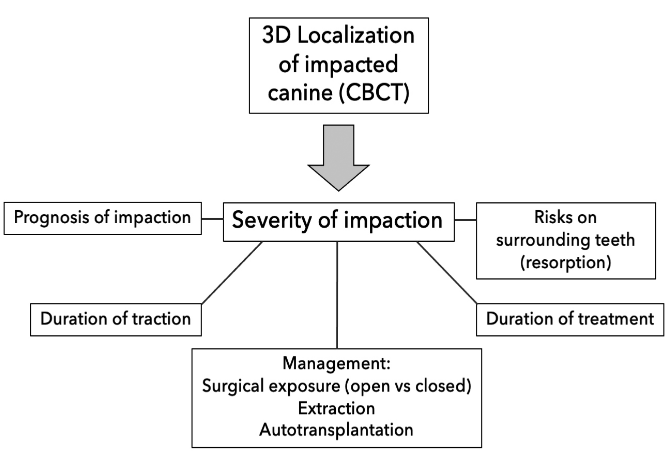

Figure 5. Illustration of the factors that are influenced by the severity of impaction based on 3D localization

CBCT, Cone-beam computed tomography

attributed to the fact that these variables were each assessed independently using (2D) radiographic images. Therefore, combining these predictive variables in one comprehensive classification system would clearly signify their value. A single predictive radiographic parameter does not necessarily illustrate the severity of impaction, but rather a combination of these variables assessed in all three planes of space–would be a reliable pretreatment estimate of orthodontic treatment duration, risks, and success rate. Moreover, with the use of a single (2D) image, a comprehensive evaluation of all these predictors at once is impossible. A combination of several (2D) images will be required. In addition, the diagnostic validity for locating impacted canines is often compromised by the drawbacks associated with (2D) images related to magnification, superimposition of adjacent structures, and the deformative nature of conventional radiographs.[45] However, with a single CBCT scan, reconstruction of the area of interest in (3D) views became a feasible and precise method to analyze all the above-mentioned radiographic predictors.[16,31,35,37]

Finally, the various proposed mechanisms for traction mentioned in the literature include the use of power chains, ligature wires, cantilever springs, accessory wires,[46] and more recently traction with the aid of temporary anchorage devices.[47] The initial eruption can be easily achieved with the use of any previously mentioned auxiliary, while, bringing the impacted canine into the line of the arch requires careful attention to the direction of pull, amount of force applied, and amount of available space in the dental arch.[48] Therefore, the implementation of a careful biomechanical approach would prevent adverse events related to root contact, periodontal health, and loss of anchorage.[43] The success in planning proper biomechanics for traction depends on using a standardized 3D analysis for localizing the impacted canine.[37] For instance, attempting to pull a palatally impacted canine with buccally directed forces without careful assessment of its 3D location in relation to the surrounding structures, might introduce unwanted side effects related to resorption and obstruction, which might hold back the eruption process and delay the treatment or lead to the loss of the impacted canine. Additionally, an optimal force system within the physiological range is needed. It was recommended that 0.6 N (61.1 grams) is the ideal force for canine traction.[1] Yadav et al.[49] discussed the forces applied in the Kilroy spring, ligature wire, and elastomeric chain systems. They concluded that the three systems produced excessive forces beyond the physiological limits 2.7 N (275.3 grams).

Interestingly, the latest literature focused on studying the influence of other factors such as the contact of the roots to the cortical plates of the nasal cavity and/or sinus, and shape of the canine's root on the success of orthodontic eruption and treatment duration. The closer the proximity of the canine's root to the cortex and the presence of a bend in the roots had a great influence on orthodontic treatment duration.[50] Therefore, many variables play a role in lengthening the treatment duration for impacted canines, all of which should be taken into consideration when evaluating treatment.

CONCLUSION

Precision in localizing an impacted maxillary canine is the key to assess its severity of impaction, which plays a main role in decision-making related to prognosis, diagnosis, treatment planning, and estimating the duration of traction. The current evidence proves the superiority of CBCT scans over conventional radiography in detection, visualization, and precisely localizing impacted canines. With a single CBCT scan, that permits reconstruction of the area under investigation in (3D) views, previously investigated radiographic predictors for the severity of impaction assessed with multiple (2D) radiographic views can now be evaluated comprehensively immediately.

An inclusive and objective analysis of (3D) locations and orientations of impacted canines based on a standardized vertical, horizontal, and angular analysis and a scoring system to determine the degree of severity is the future foundation for an accurate estimate of the duration of traction and application of proper mechanics and surgical exposure procedures necessary to resolve the impaction.

There is evidence that the impacted canine's location is the most crucial factor in determining the severity of impaction, and validation of the newly proposed severity classification using CBCT images is needed. A comprehensive nomenclature for the spatial localization of impacted canines using CBCT scans is a turnover step to facilitate communication between clinicians and aid in proper diagnosis and treatment mechanics. Despite the positive effects on treatment planning, which justifies the use of CBCT images as a routine examination for some of the impacted canine cases, it should be kept in mind that CBCT results in a higher radiation dose compared to 2D radiographs; therefore, before choosing the proper radiographical examination, both clinical benefit and radiation dose must be taken into consideration.

Ethics

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - S.A.A.; Design - P.F., S.A.A.; Supervision - S.A.A., D.K.; Data Collection and/or Processing - P.F., S.A.A.; Analysis and/or Interpretation - P.F., D.K.; Writing - P.F., S.A.A., M.N., C.D.; Critical Review - P.F., M.N., D.K., C.D., S.A.A.

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REFERENCES

1. Bishara SE. Impacted maxillary canines: a review. *Am J Orthod Dentofacial Orthop.* 1992;101(2):159-171. [CrossRef]
2. Ericson S, Kurol J. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. *Eur J Orthod.* 1988;10(4):283-295. [CrossRef]
3. Littlewood SJ, Mitchell L. An introduction to orthodontics. 5th ed. Oxford university press. 2019. [CrossRef]
4. Richardson G, Russell KA. A review of impacted permanent maxillary cuspids--diagnosis and prevention. *J Can Dent Assoc.* 2000;66(9):497-501. [CrossRef]
5. Becker A. The orthodontic treatment of impacted teeth. Martin Dunitz London. 1998. [CrossRef]
6. Becker A. Surgical exposure of impacted canines: Open or closed surgery? *Seminars in Orthodontics.* 2016;22(1):27-33. [CrossRef]
7. Fournier A, Turcotte JY, Bernard C. Orthodontic considerations in the treatment of maxillary impacted canines. *Am J Orthod.* 1982;81(3):236-239. [CrossRef]
8. Sampaziotis D, Tsolakis IA, Bitsanis E, Tsolakis AI. Open versus closed surgical exposure of palatally impacted maxillary canines: comparison of the different treatment outcomes-a systematic review. *Eur J Orthod.* 2018;40(1):11-22. [CrossRef]
9. Pitt S, Hamdan A, Rock P. A treatment difficulty index for unerupted maxillary canines. *Eur J Orthod.* 2006;28(2):141-144. [CrossRef]
10. Shin H, Park M, Chae JM, Lee J, Lim HJ, Kim BC. Factors affecting forced eruption duration of impacted and labially displaced canines. *Am J Orthod Dentofacial Orthop.* 2019;156(6):808-817. [CrossRef]
11. Ericson S, Kurol PJ. Resorption of incisors after ectopic eruption of maxillary canines: a CT study. *Angle Orthod.* 2000;70(6):415-423. [CrossRef]
12. Jacobs SG. Radiographic localization of unerupted maxillary anterior teeth using the vertical tube shift technique: the history and application of the method with some case reports. *Am J Orthod Dentofacial Orthop.* 1999;116(4):415-423. [CrossRef]
13. Southall PJ, Gravely JF. Vertical parallax radiology to localize an object in the anterior part of the maxilla. *Br J Orthod.* 1989;16(2):79-83. [CrossRef]
14. Chaushu S, Chaushu G, Becker A. The role of digital volume tomography in the imaging of impacted teeth. *World J Orthod.* 2004;5(2):120-132. [CrossRef]
15. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. *Dentomaxillofac Radiol.* 2006;35(4):219-226. Erratum in: *Dentomaxillofac Radiol.* 2006;35(5):392. [CrossRef]
16. Walker L, Enciso R, Mah J. Three-dimensional localization of maxillary canines with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop.* 2005;128(4):418-423. [CrossRef]
17. Preda L, La Fianza A, Di Maggio EM, et al. The use of spiral computed tomography in the localization of impacted maxillary canines. *Dentomaxillofac Radiol.* 1997;26(4):236-241. [CrossRef]
18. Elefteriadis JN, Athanasiou AE. Evaluation of impacted canines by means of computerized tomography. *Int J Adult Orthodon Orthognath Surg.* 1996;11(3):257-264. [CrossRef]
19. Schmuth GP, Freisfeld M, Köster O, Schüller H. The application of computerized tomography (CT) in cases of impacted maxillary canines. *Eur J Orthod.* 1992;14(4):296-301. [CrossRef]
20. Haney E, Gansky SA, Lee JS, et al. Comparative analysis of traditional radiographs and cone-beam computed tomography volumetric images in the diagnosis and treatment planning of maxillary impacted canines. *Am J Orthod Dentofacial Orthop.* 2010;137(5):590-597. [CrossRef]
21. Alqerban A, Jacobs R, Fieuws S, Willems G. Comparison of two cone beam computed tomographic systems versus panoramic imaging for localization of impacted maxillary canines and detection of root resorption. *Eur J Orthod.* 2011;33(1):93-102. [CrossRef]
22. Alqerban A, Jacobs R, Fieuws S, Willems G. Radiographic predictors for maxillary canine impaction. *Am J Orthod Dentofacial Orthop.* 2015;147(3):345-354. [CrossRef]
23. Grünheid T, Kolbeck Schieck JR, Pliska BT, Ahmad M, Larson BE. Dosimetry of a cone-beam computed tomography machine compared with a digital x-ray machine in orthodontic imaging. *Am J Orthod Dentofacial Orthop.* 2012;141(4):436-443. [CrossRef]
24. Schulze RKW, Drage NA. Cone-beam computed tomography and its applications in dental and maxillofacial radiology. *Clin Radiol.* 2020;75(9):647-657. [CrossRef]
25. Eslami E, Barkhordar H, Abramovitch K, Kim J, Masoud MI. Cone-beam computed tomography vs conventional radiography in visualization of maxillary impacted-canine localization: A systematic review of comparative studies. *Am J Orthod Dentofacial Orthop.* 2017;151(2):248-258. [CrossRef]
26. Rossini G, Cavallini C, Cassetta M, Galluccio G, Barbato E. Localization of impacted maxillary canines using cone beam computed tomography. Review of the literature. *Ann Stomatol (Roma).* 2012;3(1):14-18. [CrossRef]
27. Lindauer SJ, Rubenstein LK, Hang WM, Andersen WC, Isaacson RJ. Canine impaction identified early with panoramic radiographs. *J Am Dent Assoc.* 1992;123(3):91-92, 95-7. Erratum in: *J Am Dent Assoc.* 1992;123(5):16. [CrossRef]
28. Warford JH Jr, Grandhi RK, Tira DE. Prediction of maxillary canine impaction using sectors and angular measurement. *Am J Orthod Dentofacial Orthop.* 2003;124(6):651-655. [CrossRef]
29. Power SM, Short MB. An investigation into the response of palatally displaced canines to the removal of deciduous canines and an assessment of factors contributing to favourable eruption. *Br J Orthod.* 1993;20(3):215-223. [CrossRef]
30. Fleming PS, Scott P, Heidari N, Dibiase AT. Influence of radiographic position of ectopic canines on the duration of orthodontic treatment. *Angle Orthod.* 2009;79(3):442-446. [CrossRef]
31. Kau CH, Pan P, Gallerano RL, English JD. A novel 3D classification system for canine impactions--the KPG index. *Int J Med Robot.* 2009;5(3):291-296. [CrossRef]
32. Kau CH, Lee JJ, Souccar NM. The validation of a novel index assessing canine impactions. *Eur J Dent.* 2013;7(4):399-404. [CrossRef]
33. Dalessandri D, Migliorati M, Rubiano R, et al. Reliability of a novel CBCT-based 3D classification system for maxillary canine impactions in orthodontics: the KPG index. *Scientific World Journal.* 2013;2013:921234. [CrossRef]
34. Liu DG, Zhang WL, Zhang ZY, Wu YT, Ma XC. Localization of impacted maxillary canines and observation of adjacent incisor resorption

with cone-beam computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2008;105(1):91-98. [CrossRef]

35. Zeno KG, Ghafari JG. Palatally impacted canines: A new 3-dimensional assessment of severity based on treatment objective. *Am J Orthod Dentofacial Orthop.* 2018;153(3):387-395. [CrossRef]
36. Chaushu S, Chaushu G, Becker A. The use of panoramic radiographs to localize displaced maxillary canines. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1999;88(4):511-516. [CrossRef]
37. Ross G, Abu Arqub S, Mehta S, et al. Estimating the 3-D location of impacted maxillary canines: A CBCT-based analysis of severity of impaction. *Orthod Craniofac Res.* 2023;26(1):81-90. [CrossRef]
38. Zuccati G, Ghobadlu J, Nieri M, Clauser C. Factors associated with the duration of forced eruption of impacted maxillary canines: a retrospective study. *Am J Orthod Dentofacial Orthop.* 2006;130(3):349-356. [CrossRef]
39. Stewart JA, Heo G, Glover KE, Williamson PC, Lam EW, Major PW. Factors that relate to treatment duration for patients with palatally impacted maxillary canines. *Am J Orthod Dentofacial Orthop.* 2001;119(3):216-225. [CrossRef]
40. Ericson S, Kurol J. Radiographic assessment of maxillary canine eruption in children with clinical signs of eruption disturbance. *Eur J Orthod.* 1986;8(3):133-140. [CrossRef]
41. Leonardi M, Armi P, Franchi L, Baccetti T. Two interceptive approaches to palatally displaced canines: a prospective longitudinal study. *Angle Orthod.* 2004;74(5):581-586. [CrossRef]
42. Dubovská MI, Urbanová MW, Sedlatá–Jurásková ME, et al. Palatally impacted canines: factors affecting treatment duration on lateral cephalograms. Palatally impacted canines: factors affecting treatment duration on lateral cephalograms. *IOSR Journal of Dental and Medical Sciences.* 2015;14(10):13-17. [CrossRef]
43. Fleming PS, Sharma PK, DiBiase AT. How to...mechanically erupt a palatal canine. *J Orthod.* 2010;37(4):262-271. [CrossRef]
44. Schmidt AD, Kokich VG. Periodontal response to early uncovering, autonomous eruption, and orthodontic alignment of palatally impacted maxillary canines. *Am J Orthod Dentofacial Orthop.* 2007;131(4):449-455. [CrossRef]
45. Giles SA, Taylor NG. Are anterior occlusal radiographs still indicated for orthodontic assessment? *Br Dent J.* 1997;183(9):325-328. [CrossRef]
46. Yadav S, Nanda R. Biomechanics-Based Management of Impacted Canines. Esthetics and Biomechanics in Orthodontics. 2012;121-132. [CrossRef]
47. Venugopal A, Vaid NR. Interarch Traction Strategy for Palatal Cuspid Impactions. *J Contemp Dent Pract.* 2020;21(12):1408-1411. [CrossRef]
48. Iancu Potrubacz M, Chimenti C, Marchione L, Tepedino M. Retrospective evaluation of treatment time and efficiency of a predictable cantilever system for orthodontic extrusion of impacted maxillary canines. *Am J Orthod Dentofacial Orthop.* 2018;154(1):55-64. [CrossRef]
49. Yadav S, Chen J, Upadhyay M, Jiang F, Roberts WE. Comparison of the force systems of 3 appliances on palatally impacted canines. *Am J Orthod Dentofacial Orthop.* 2011;139(2):206-213. [CrossRef]
50. Amuk M, Gul Amuk N, Ozturk T. Effects of root-cortex relationship, root shape, and impaction side on treatment duration and root resorption of impacted canines. *Eur J Orthod.* 2021;43(5):508-515. [CrossRef]