ISSN: 1110-435X
ONLINE ISSN: 281-5258

Egyptian
Orthodontic Journal

Effect of maxillary sinus proximity on upper molar movement during distalization with clear aligner therapy: a retrospective study

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Abstract

Background: The objective of this study was to assess the correlation between maxillary sinus proximity to root apices of maxillary molars and changes in molar angulation (tipping), inclination (torque), and rotation during molar distalization using clear aligner therapy (CAT).

Methods: This study evaluated 38 cone beam computed tomography (CBCT) images obtained pre (T0) and post (T1) treatment from 19 adult patients who underwent maxillary molar distalization using Invisalign aligners (Align Technology, Inc., San José, CA, USA) with at least 2mm distalization. Only those who wore the aligner for at least 22 hours daily were included in the study. Sinus proximity and the changes in tip, torque and rotation were measured for 61 molars. Spearman coefficient analysis was used to appraise the correlation between sinus proximity and each of the other measured variables. The level of significance was set at $p \leq 0.05$. The reproducibility of measurements was assessed by the intraclass correlation coefficient (ICC).

Results: Spearman coefficient revealed a significant positive correlation between maxillary sinus proximity to root apices and molar inclination (buccal crown torque) ($p=0.044$). Palatal root proximity to the sinus was the only individual root eliciting a positive correlation with molar inclination ($p=0.022$). No significant correlation was found between sinus proximity and molar angulation (tipping) nor rotation ($p= 0.381$ and $p=0.124$, respectively).

Conclusion: Proximity of maxillary molars root apices to the maxillary sinus causes more buccal crown torque during distalization using CAT, while it has no significant effect on molar tipping nor rotation.

Keywords: Maxillary sinus proximity, Clear aligner, Distalization, Angulation, Inlcination, Rotation.

Introduction

The alveolar process and a part of the hard palate [(1)] combine to generate dense cortical bone that makes up the floor of the maxillary sinus. Since cortical bone turnover is slower than trabecular bone turnover [(2,3)], tooth movement in the cortical bone is considered an anatomical limitation in orthodontic therapy for adults. About half of adults have sinus invasion into the maxillary alveolar process, with root apices of the maxillary second premolar and first and second permanent molars protruding into the sinus due to age-related pneumatization [(4,5)]. Maxillary sinus pneumatization increases with higher alveolar ridge atrophy classes,

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which are primarily found in elderly patients (6), due to prolonged edentulism and consequent alveolar ridge resorption [7,8]. Moreover, sinus pneumatization (the sinking of the sinus bottom) plays an important role in increasing alveolar ridge atrophy from the cranial direction (atrophy-induced pneumatization) [9].

Sun et al. (10) conducted a systematic study to assess the viability, safety, and stability of current techniques for moving teeth through the maxillary sinus. Nine case reports were included in the review, with only two making use of cone beam computed tomography (CBCT). They showed that it is possible and safe to gradually move teeth through the maxillary sinus in adults by applying continuous light to moderate pressures. They acknowledged the possibility of physical movement but noted that, at first, teeth appear to be easily tipped, which could lead to root resorption. Some studies have suggested that variable degrees of tipping may occur during horizontal movement of the tooth across the sinus floor [10-12]. A finite element analysis showed that the simultaneous penetration of all three roots of the maxillary first molar into the sinus created a bicortical anchorage effect and reduced the moment-to-force (M/F) ratio [13].

Due to its superior aesthetics [14] and comfort [15], clear aligner therapy (CAT) has made a significant impact since its introduction to orthodontics. Aligners were originally marketed as an alternate treatment for moderate crowding or space closure; but, with the development of new technologies and products, they are also being considered as a treatment option for complex cases requiring extraction and distalization [16]. Simon et al. [17] postulated that molar distalization can be accomplished using the Invisalign clear aligners system It has been observed that using orthodontic clear aligners for maxillary molar distalization offers vertical dimension control [18]. A systematic review by Rossini et al. [19] concluded that CAT is effective in controlling upper molar bodily movement when a distalization of 1.5 mm has been prescribed, and Ravera et al. (20) found that 2.25 mm maxillary molar distalization can be achieved without significant molar tipping.

However, no previous studies have investigated the possibility that maxillary sinus proximity to the root apices of maxillary molars might affect molar movement during their distalization using CAT. Therefore, the aim of this study was to evaluate the effect of maxillary sinus proximity to the root apices of maxillary molars during their distalization by Invisalign clear aligners on maxillary molar angulation, inclination, and rotation using three-dimensional cone beam computed tomography (3D CBCT).

Materials and methods

Sampling

The sample size of this retrospective study was estimated assuming 5% alpha error and 80% study power. The mean and standard deviation (SD) values for the difference in molar tipping after treating patients with aligners were 0.4825 (1.08) mm according to Ravera et al. [20]. Based on the difference between the two dependent means, the minimum sample size was calculated to be 44 molars. The sample size was based on Rosner's method [21], calculated by G power 3.0.10 [22].

Ethical approval was obtained from the Ethics Review Committee of the Faculty of Dentistry, Alexandria University, Alexandria, Egypt (IRB:00010556- IORG:0008839). All records were of patients who consented to the use of records for research or educational purposes following the ethical approval at the University of Alberta, protocol # (Pro00091339). All records were anonymous before being enrolled in the study.

We included adult patients who received standardized treatment protocols for maxillary sequential molar distalization, and showed compliance by wearing aligners for at least 22 hours daily, as per recommendations by Invisalign (Align technology, Inc., San Jose, CA, USA) with regular monitoring over six weeks for encouragement. Moreover, a minimum of 2 mm actual molar distalisation measured on CBCT was mandatory. Those with previous orthodontic treatment, systemic diseases, craniofacial syndromes or cleft were excluded.

A total of 38 cone beam computed tomography scans (CBCTs) were taken from 19 adult patients managed using molar distalization Invisalign by the same orthodontics in a single institute. While all the scans were taken pre- (T0) and post-treatment (T1), this study enrolled 61 maxillary molars, totaling 183 roots. The same CBCT scanner (i-CAT, Imaging Sciences International (ISI), PA, USA) was utilized for all CBCT images in agreement with manufacturers' recommendations (8.9 s, 13 x16 cm FOV, 120 k, 10 mA and 360° rotation, and voxel size 0.3 mm). The heads of the enrolled participants were positioned in a way that the Frankfort horizontal plane was parallel to the floor Digital Imaging and Communications in Medicine (DICOM) format was used to save the images.

CBCT image analysis

Pre- and post- treatment digital CBCT images were assessed using the Dolphin Imaging software v.11.95 Premium (Dolphin Imaging, Chatsworth, CA) at Mohamed bin Rashid University (MBRU). In each image, the mid-sagittal plane was placed perpendicular to the Nasion in the coronal and sagittal views (Figure1,A-B). For measuring the amount of molar distalization and molar angulation, the axial plane was oriented through Frankfort horizontal plane on the sagittal view. While, to consistently measure the molar rotation, it was reoriented to pass through the occlusal plane (Figure1,C-D).

Sagittal images of CBCT were used to measure sinus proximity, amount of molar distalization, molar angulation (mesiodistal tipping). Two sagittal sections were used, one showing the mesiobuccal (MB) and distobuccal (DB) root apices, and another showing the palatal (Pa) root apex. Coronal slices were used to measure the molar inclination (Bucco-lingual torque), while axial slices were used to measure molar rotation. Measurements were performed by the same investigator using the measurement tool in Dolphin Imaging software.

Dental measurements

The amount of maxillary molar distalization was measured using CBCT-driven images in the sagittal plane, and linear measurements were taken from the mesiobuccal cusp of the maxillary first molar and mesiobuccal cusp of the maxillary second molar to the coronal plane at (T0) and (T1) (respectively).

CBCT was used to assess the level of the maxillary sinus proximity to maxillary molars. The distance between the root apex of the maxillary molar and the inferior wall of the maxillary sinus, the apex-sinus distance (ASD), was measured in the sagittal images. Measurements were made according to the following types: Type I: The shortest perpendicular distance between the root apex and the inferior wall of the maxillary sinus was measured if the roots had no contact with its wall. Type II: the distance was considered as zero if there was contact between the root and the inferior wall, Type III: The distance from the root apex to the lower border of the maxillary sinus was measured on a midpoint on each root if the root protruded into the maxillary sinus. If there was no contact between the root and the floor of the maxillary sinus, the distance was regarded as a negative value, whilst a positive value was considered if the root protruded into the maxillary sinus [23]. The same principle was applied for the (MB), (DB) and (Pa) roots of the maxillary molars (Figure 2).

Molar angulation (mesiodistal tipping) was measured on the sagittal views as the angle between the long axis of the maxillary molar (i.e., the line passing through molar bifurcation and Frankfurt horizontal plane (FHP). This was repeated on pre- and post-treatment CBCTs (Figure 3). Molar inclination (bucco-lingual inclination) was measured on the coronal sections as the angle between a line connecting the buccal cusp tip and the palatal root apex and the FHP (Figure 4). This was repeated on pre- and post-treatment CBCTs.

Molar rotation

The CBCT orientation was changed such that the axial plane went across the occlusal plane in order to assess molar rotation. On the axial images, molar rotation was measured as angle between the line connecting the MB and DB cusps and the mid-sagittal plane (Figure 5).

Statistical analysis

Statistical analysis was carried to study the correlation between ASD and the type of molar movement, and root resorption. Ten CBCTs were utilized to calibrate the researcher before the actual investigation was done. Repeated attempts at taking the measurements were made until an adequate level of agreement was obtained. To investigate intra-rater repeatability, all parameters were examined a second time by the same examiner one week apart, with differences summarized using summary statistics and intraclass correlation coefficients (ICCs) were calculated. Quantitative data were described using range (minimum and maximum), mean, and standard deviation. The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to verify the normality of distribution. Spearman coefficient was used to correlate the maxillary sinus proximity and the change in the pre- and post-treatment molar angulation, inclination, rotation, and root resorption, with $p \leq 0.05$ indicating statistical significance.

Results

The ICC showed Excellent reproducibility for linear measurements (0.94-0.99) and angular measurements (0.86-0.99) were shown by ICC [24]. As regards correlations between the maxillary sinus proximity and type of molar movement, a positive correlation was found between the average root proximity to maxillary sinus and molar inclination (buccal crown torque) (p=0.044). Furthermore, the palatal root was the only root whose individual proximity to the sinus was positively correlated with molar inclination (p=0.022). No significant correlation was present between sinus proximity and molar angulation (tipping) nor rotation (p=0.381 and p=0.124, respectively) (Table 1).

Discussion

Class II non-extraction patients with minimal skeletal discrepancies often require distalization of maxillary molars to resolve Class II molar relationship [25]. When a mean molar distalization movement of 2.25 to 2.6 mm is required, sequential molar distalization can be performed effectively with aligners nowadays [20,26] . However, the proximity of maxillary sinus to molar roots apices during molar distalization and its effect on the type of molar movement has not been documented.

The availability of pre- and post-treatment CBCT records with great specificity [27], allowed for accurate evaluation of sinus proximity to root apices and type of molar movement in our study. In addition, the type of molar movement is best evaluated using CBCT rather than using the Clincheck with no roots represented, or the two dimensional (2D) lateral cephalometry, with its limitation of superimposition of right and left molars. Recent advancements in CBCT technology have also allowed the method to be more affordable for the dental office, and to be safer for the patient, due to decreased exposure to ionizing radiation [28].

One of the merits of the present study was the feasibility of measurement of molar inclination (torque), which could only be measured on the coronal section of 3D-CBCT, as it cannot be assessed on 2D images like panoramic or cephalometric radiographs. This seems to be the first study to evaluate the torque during molar distalization using aligner therapy, which could be attributable to the scarcity of CBCT records before and after treatment with CAT. This research revealed a positive correlation between maxillary sinus proximity to maxillary molar root apices and crown inclination (buccal crown torque). Finite element analysis for upper molar distalization concluded that bodily distal upper molar movement could be obtained only when rotational axis is at infinite, and the compressive stress is homogeneously distributed in the periodontal ligament [29]. Thus, it is recommended in cases requiring maxillary molar distalization using clear aligners to add molars' attachments, to control buccal flaring, especially in cases of maxillary sinus proximity. Interestingly, when individual molar root proximity to the maxillary sinus was investigated, the palatal root sinus proximity was the only one positively correlated with crown inclination. This might be due to the girth of the palatal root penetrating the maxillary sinus, thereby undermining its anchoring effect in the bone, consequently reducing torque control.

Sinus proximity showed no significant correlation with molar tipping during distalization using CAT. Somewhat similar results were reported by Kim et al. [30], who studied the effect of maxillary arch distalization using a modified C-palatal plate in patients with Class II malocclusion with sinus pneumatization, and concluded that there was no significant difference in the amount of tooth movement in the anteroposterior direction between the two groups with and without sinus pneumatization. Theoretically speaking, it was proposed that the distribution of bone density in the maxillary sinus along the axis of a tooth must be considered and that the coronal part of the root is more likely to move against cancellous bone, while the apical part is more likely to move against cortical bone, but this has not been proven by any study [31]. Molar rotation did not seem to be affected by proximity of molars' roots to the maxillary sinus, as evidenced by the lack of correlation in CBCT measurements.

Conclusion

1. Proximity of maxillary first and second molar root apices to the maxillary sinus causes significant buccal crown torque during molar distalization using CAT.
2. The molars' palatal roots were the only roots whose proximity to the maxillary sinus was positively correlated with crown inclination (torque) during molar distalization using CAT.
3. Maxillary sinus proximity has no significant correlation with molar tipping nor rotation during molar distalization using CAT.

Conflict of interest statement

Authors declare no conflict of interest

Funding

There was no funding source for this study.

Abbreviations

CAT: Clear aligner therapy, 3D CBCT: Three-dimensional cone beam computed tomography, MB: Mesiobuccal, DB: Distobuccal, Pa: Palatal, ASD: Apex-sinus distance, FHP: Frankfurt horizontal plane, 2D: Two dimensional. ICCs: Intraclass correlation coefficients

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

DE: conceptualization, methodology, investigation, visualization, and writing original draft.
HI: methodology, writing, reviewing, and editing.
NE: conceptualization, methodology, visualization, and writing original draft.
TE: conceptualization, methodology, resources, writing, reviewing, and editing.
AG: conceptualization, methodology, software, validation, writing, reviewing, and editing.
All authors read and approved the final manuscript.

References

1. McGrowan D, Baxter P, James J. The maxillary sinus and its dental implications. 1st ed. London (UK): Wright; 1993.

2. Verna C, Melsen B, Melsen F. Differences in static cortical bone re-modeling parameters in human mandible and iliac crest. Bone 1999;25:577-83.

3. Birte M. Adult orthodontics. London (UK): Wiley-Blackwell; 2012.

4. Ariji Y, Kuroki T, Moriguchi S, Ariji E, Kanda S. Age changes in the volume of the human maxillary sinus: a study using computed tomography Dentomaxillofac Radiol 1994;23:163-8.

5. Lorkiewicz-Muszyńska D, Kociemba W, Rewekant A, Sroka A, Jończyk-Potoczna K, Patelska-Banaszewska M, Przystańska A. Development of the maxillary sinus from birth to age 18. Postnatal growth pattern. Int J Pediatr Otorhinolaryngol. 2015 Sep;79(9):1393-400.

6. Wagner F, Dvorak G, Nemec S, Pietschmann P, Traxler H, Schicho K, Seemann R (2017) Morphometric analysis of sinus depth in the posterior maxilla and proposal of a novel classification. Sci Rep 7: 45397. https://doi.org/10.1038/srep45397

7. Reich KM, Huber CD, Lippnig WR, Ulm C, Watzek G, Tangl S (2011) Atrophy of the residual alveolar ridge following tooth loss in an historical population. Oral Dis 17(1):33–44. https://doi.org/10.1111/j.1601-0825.2010.01699.x

8. Abdalla MA. Human Maxillary Sinus Development, Pneumatization, Anatomy, Blood Supply, Innervation and Functional Theories: An Update Review. Siriraj Medical Journal. 2022 Jul 1;74(7):472-9.

9. Gerken U, Esser F, Möhlhenrich SC, Bartella AK, Hölzle F, Fischer H, Raith S, Steiner T. Objective computerised assessment of residual ridge resorption in the human maxilla and maxillary sinus pneumatisation. Clinical oral investigations. 2020 Sep;24(9):3223-35.

10. Sun W, Xia K, Huang X, Cen X, Liu Q, Liu J. Knowledge of orthodontic

tooth movement through the maxillary sinus: a systematic review. BMC Oral Health 2018;18:91.

11. Wehrbein H, Bauer W, Wessing G, Diedrich P. The effect of the maxillary sinus floor on orthodontic tooth movement. Fortschr Kieferorthop 1990;51:345-51.

12. Wehrbein H, Bauer W, Schneider B, Diedrich P. Experimental bodily tooth movement through the bony floor of the nose—a pilotstudy. Fortschr Kieferorthop 1990;51:271-6.

13. Camcı H, Salmanpour F. Effect of sinus proximity, alveolar bone level, and initial buccolingual inclination on behavior of maxillary first molar under expansion force: a finite element analysis. J World Fed Orthod 2022;11:60-7.

14. Walton DK, Fields HW, Johnston WM, Rosenstiel SF, Firestone AR, Christensen JC. Orthodontic appliance preferences of children and adolescents. Am J Orthod Dentofacial Orthop 2010;138:698.e1-12; discussion, 698-9.

15. Fujiyama K, Honjo T, Suzuki M, Matsuoka S, Deguchi T. Analysis of pain level in cases treated with Invisalign aligner: comparison with fixed edgewise appliance therapy. Prog Orthod 2014;15:64.

16. Womack WR. Four-premolar extraction treatment with Invisalign. J Clin Orthod 2006;40:493-500.

17.Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique–regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health 2014;14:1-7.

18. Caruso S, Nota A, Ehsani S, Maddalone E, Ojima K, Tecco S. Impact of molar teeth distalization with clear aligners on occlusal vertical dimension: a retrospective study. BMC Oral Health 2019;19:182.

19. Gabriele Rossini, Simone Parrini, Tommaso Castroflorio, Andrea Deregibus, Cesare L. Debernardi; Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review. Angle Orthod 1 September 2015; 85 (5): 881–889. doi: https://doi.org/10.2319/061614-436.1

20. Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, Deregibus A. Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study. Prog Orthod 2016;17:1-9.

21. Rosner B. Hypothesis Testing: Two-Sample Inference. In: Fundamentals of biostatistics. 7th ed. Boston: Brooks/Cole. Nelson Education; 2015. pp 269-301.

22. Universität Düsseldorf. G*Power.2019. Retrieved from http://www.gpower.hhu.de/

23. Oishi S, Ishida Y, Matsumura T, Kita S, Sakaguchi-Kuma T, Imamura T, et al. A cone-beam computed tomographic assessment of the proximity of the maxillary canine and posterior teeth to the maxillary sinus floor: Lessons from 4778 roots. Am J Orthod Dentofacial Orthop 2020;157:792-802.

24. Bartko JJ. The intraclass correlation coefficient as a measure if reliability. Psychol Rep. 1966;19:3-11.

25. Bolla E, Muratore F, Carano A, Bowman SJ. Evaluation of maxillary molardistalization with the distal jet: a comparison with other contemporary methods. Angle Orthod. 2002;72:481–94.

26. Saif BS, Pan F, Mou Q, Han M, Bu W, Zhao J, et al. Efficiency evaluation of maxillary molar distalization using Invisalign based on palatal rugae registration. *Am J Orthod Dentofacial Orthop.* 2022;161:e372-e379.

27. Ren H, Chun J, Deng F, Zheng L, Liu X, Dong Y. Comparison of cone-beam computed tomography and periapical radiography for detecting simulated apical root resorption. Angle Orthod 2013;83:189-95.

28. Venkatesh E, Elluru SV. Cone beam computed tomography: basics and applications in dentistry. Journal of istanbul University faculty of Dentistry. 2017;51(3 Suppl 1):S102.

29. Mariana LI. Finite element analysis for upper molar distalization. Romanian J Oral Rehabil. 2012 Jul;4(3).

30. Kim S, Lee NK, Park JH, Ku JH, Kim Y, Kook YA, Chou AH, Vaid NR. Treatment effects after maxillary total arch distalization using a modified C-palatal plate in patients with Class II malocclusion with sinus pneumatization. American Journal of Orthodontics and Dentofacial Orthopedics. 2022 Jun 27.

31. Proffit WR, Fields HW Jr, Sarver DM. Contemporary orthodontics. 4th ed. St Louis: C.V. Mosby; 2007. p. 287-300–331–430

Figures legends:

Figure 1: CBCT images were oriented with the midsagittal plane aligned to nasion perpendicular (A-D) and the axial plane aligned to either FHP (A-B) or occlusal plane (C-D) to consistently measure the selected parameters that are related to each orientation.

Figure 2: ASD, apex-sinus distance; Type I (A), Type II (B) and Type III (C).

Figure 3:. Measurement of maxillary first permanent molar angulation.

Figure 4:. Measurement of maxillary first permanent molar Inclination.

Figure 5: Molar Rotation measurement on axial view.

Table 1: Correlation between maxillary sinus proximity to root apices (mm) and change in molar angulation, inclination and rotation °.

	Sinus proximity to molars apices (mm)							
	MB		DB		Pa		Average (all roots)	
	r_s	p	r_s	p	r_s	p	r_s	p
Change in molar angulation °	-0.098	0.453	-0.113	0.385	-0.114	0.382	-0.114	0.381
Change in molar inclination °	0.175	0.177	0.225	0.081	0.294	0.022*	0.259	0.044*
Change in molar rotation °	-0.199	0.124	-0.16°3	0.209	-0.188	0.147	-0.199	0.124

r_s: Spearman coefficient

*: Statistically significant at $p \leq 0.05$

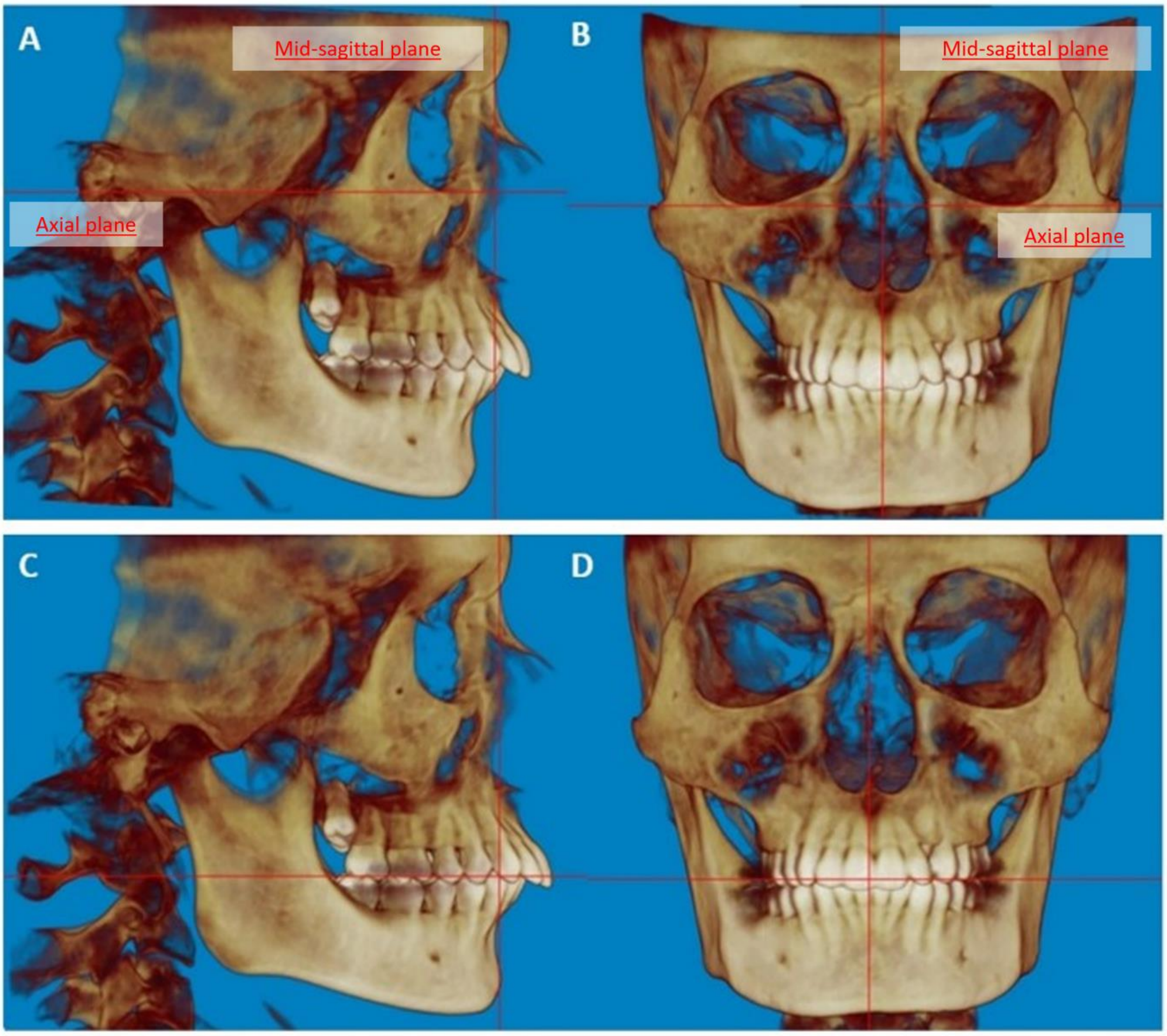

Figure 1: CBCT images were oriented with the midsagittal plane aligned to nasion perpendicular (A-D) and the axial plane aligned to either FHP (A-B) or occlusal plane (C-D) to consistently measure the selected parameters that are related to each orientation.

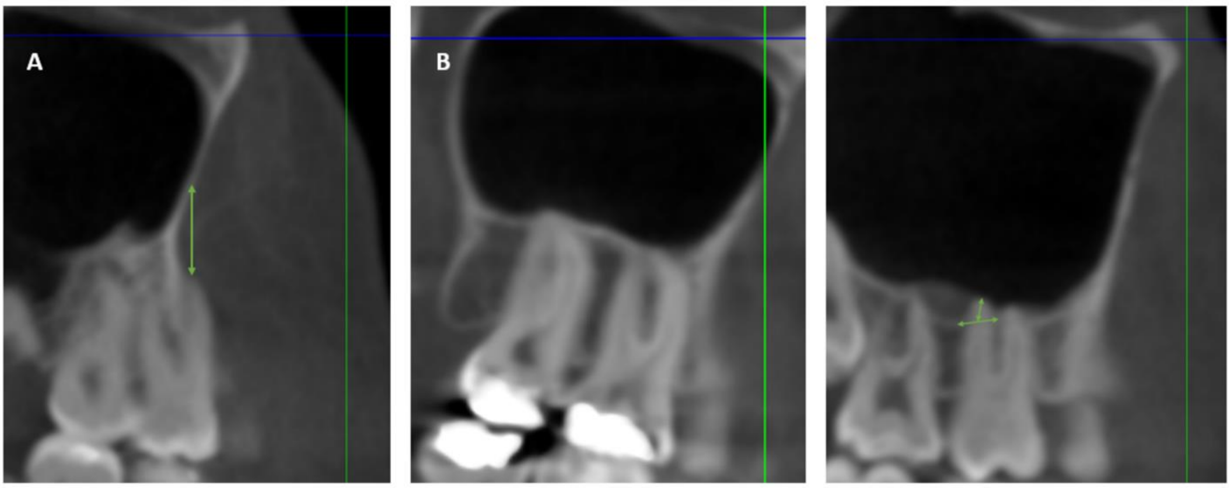

Figure 2: ASD, apex-sinus distance; Type I (**A**), Type II (**B**) and Type III (**C**).

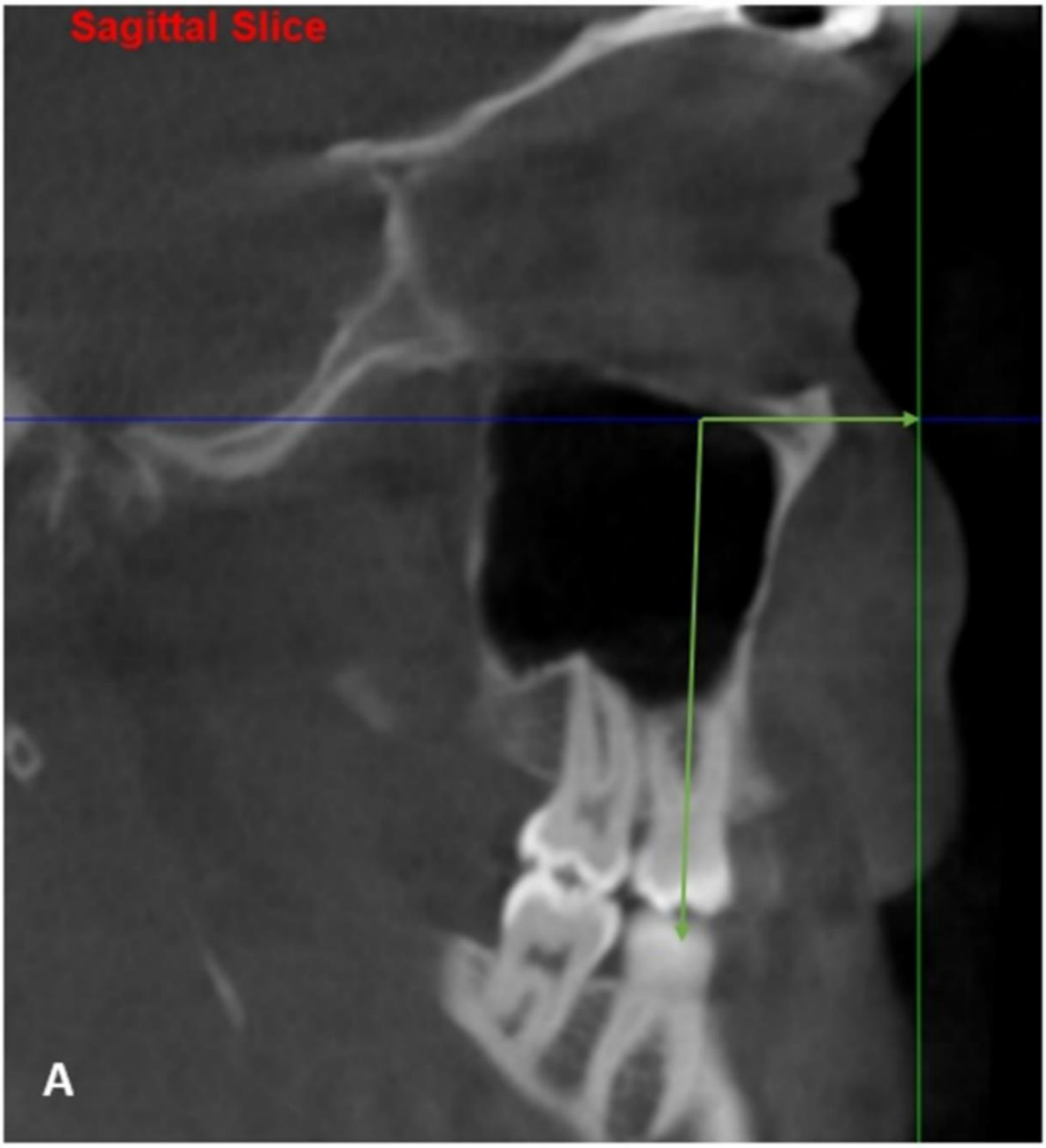

Figure 3:. Measurement of maxillary first permanent molar angulation.

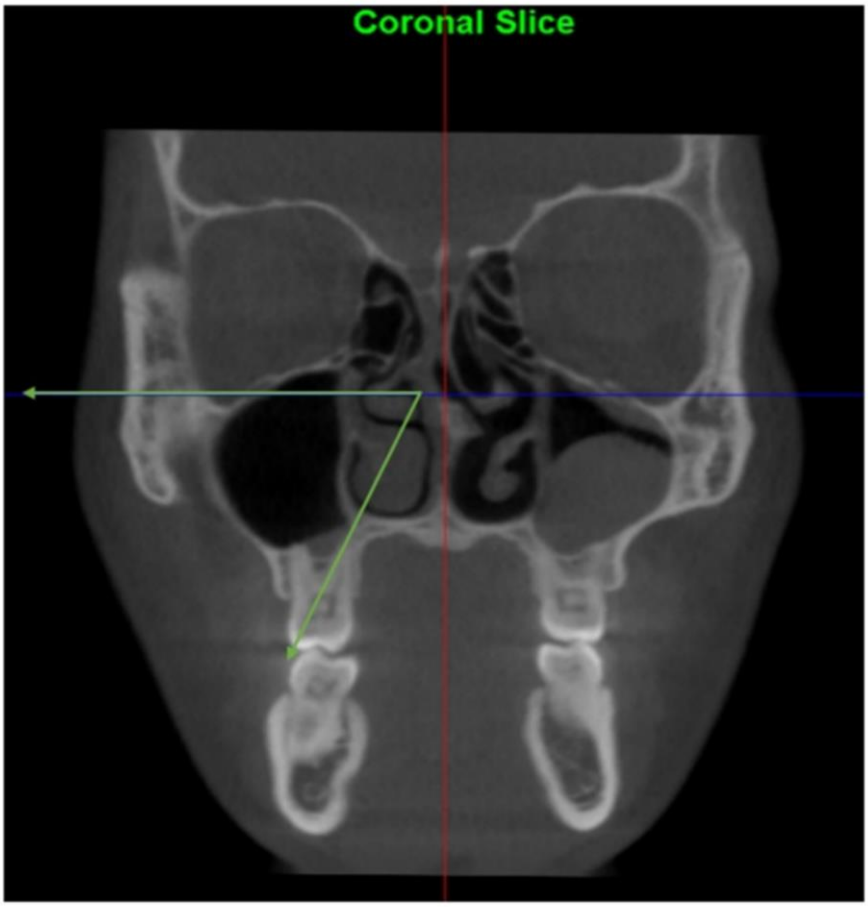

Figure 4:. Measurement of maxillary first permanent molar Inclination.

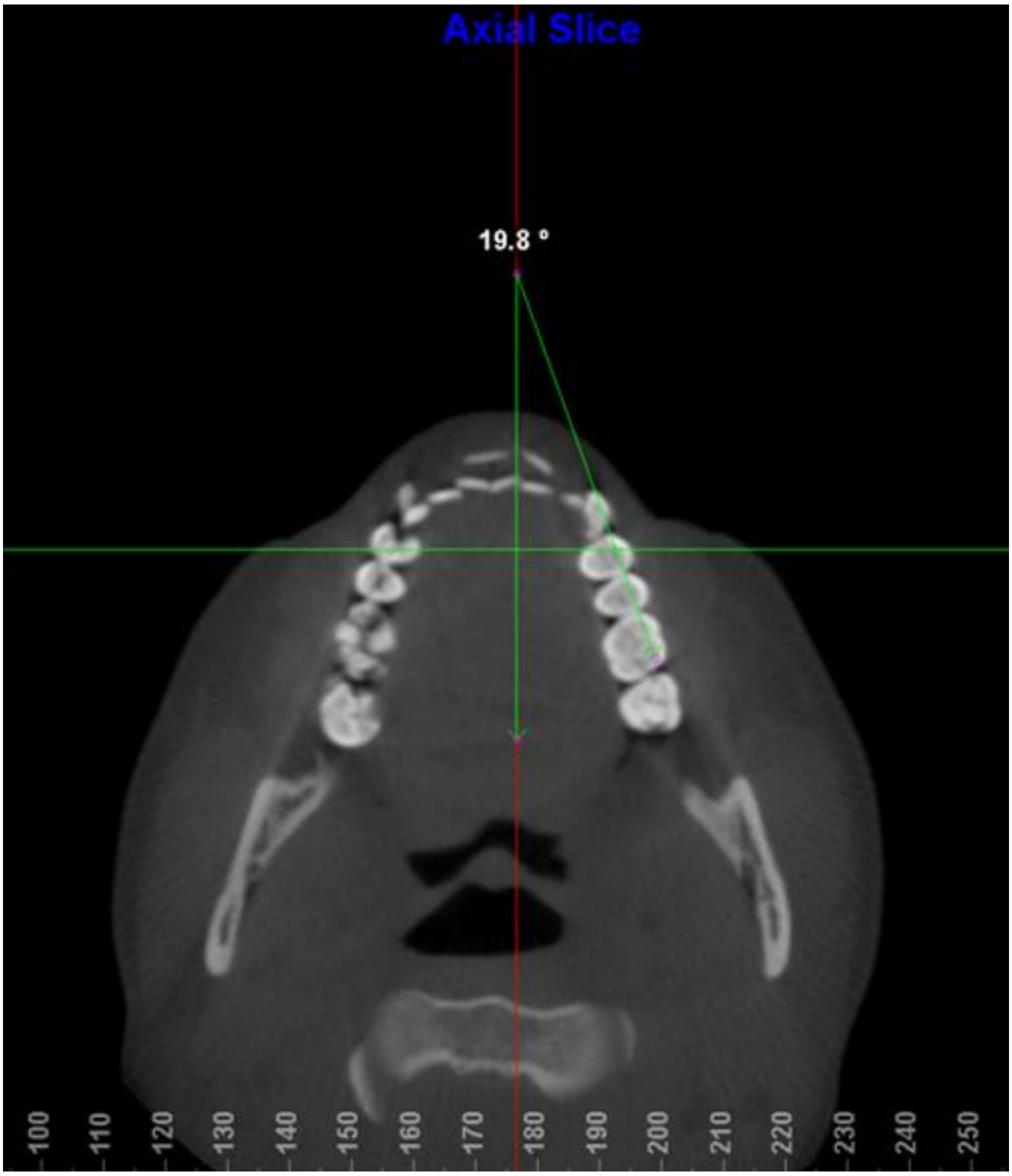

Figure 5: Molar Rotation measurement on axial view.