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ORIGINAL RESEARCH

THE IMPACT OF VOLUME ORIENTATION ANGLE IN THE SAGITTAL PLANE ON THE MEASUREMENT OF ALVEOLAR BONE WIDTH IN THE POSTERIOR MANDIBLE USING CBCT

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ABSTRACT

Background and Objective: Linear measurements of alveolar bone using cone-beam computed tomography (CBCT) may potentially be influenced by the sagittal volume orientation during image reconstruction. Considering the clinical importance of measurement accuracy in implant surgery, this study aimed to evaluate the effect of sagittal reconstruction angle of CBCT on alveolar ridge width in the posterior mandible of subjects with a normal facial pattern. **Materials and Methods:** In this cross-sectional study, 165 CBCT scans were selected. During the reconstruction phase, the sagittal plane was oriented at seven different angles (from OP to OP + 30° in 5° intervals), and alveolar ridge width was measured at each angle. Data were analyzed using SPSS version 26 with repeated-measures ANOVA, Bonferroni post-hoc tests, and the intraclass correlation coefficient (ICC) with a significance level of 0.05. **Results:** Sagittal volume orientation significantly affected the measured alveolar ridge width ($p < 0.001$). With increasing angles from OP to OP + 15°, the mean ridge width increased progressively from 11.18 ± 1.60 mm to 12.00 ± 1.59 mm, remaining nearly constant at higher angles. The maximum width was observed at OP + 30° (12.07 ± 1.58 mm), which was significantly greater than other angles ($p < 0.001$). **Conclusion:** Increasing the sagittal reconstruction angle of CBCT volumes significantly increases measured alveolar bone width in the posterior mandible. Rotating the volume from the occlusal plane toward the mandibular plane produced a progressive and clinically relevant widening, with OP to OP+15° yielding approximately 0.8–0.9 mm of additional width. This effect results from posterior displacement of the cross-sectional plane, which intersects broader regions of the mandibular body as the orientation angle increases.

Keywords*:* Cone-Beam Computed Tomography, Volume Orientation, Linear Measurement, Alveolar Bone Width, Implant.

INTRODUCTION

Cone-beam computed tomography (CBCT) has become a widely used imaging modality across various dental specialties due to its three-dimensional capabilities and relatively low radiation dose compared with conventional CT, overcoming many limitations inherent to two-dimensional radiography [1-3]. CBCT is currently considered the preferred method for pre-implant assessment, maxillofacial evaluation, orthodontic analysis, and endodontic treatment planning [3-5]. Accurate determination of alveolar bone height and width is essential before implant placement to avoid complications involving vital anatomical structures and to ensure proper selection of implant dimensions [1,6]. Alveolar bone width is typically defined as the distance between the buccal and lingual cortical plates, and maintaining dimensional accuracy is a fundamental requirement in CBCT-based morphometric analyses [7].
Although several investigations have confirmed the general reliability of CBCT-derived linear

measurements [8,9], discrepancies still occur in clinical practice due to factors such as patient motion, exposure settings, software reconstruction errors, and variability among CBCT units [10]. One factor that has recently received significant attention is head orientation during image acquisition, as deviations from the ideal position may alter the spatial relationship of anatomical structures within the reconstructed volume and potentially affect linear measurements [11,12]. Despite CBCT devices being equipped with positioning aids such as chin rests and head supports, improper posture is still frequently encountered in routine imaging [6,13]. As a result, most CBCT viewing platforms offer a "volume orientation" feature that enables post-acquisition adjustment of head position prior to generating cross-sectional reformations [6, 14].The potential clinical relevance of CBCT volume orientation has been highlighted in previous research. Costa et al. evaluated whether modifying the sagittal orientation of the CBCT volume by aligning either the occlusal plane or the mandibular plane parallel to the horizontal reference would influence alveolar bone measurements for implant planning [6]. Their sample included 74 individuals classified into mesoarial, brachyfacial, and dolichofacial profiles. The authors reported that when the volume was re-oriented parallel to the mandibular plane, the measured alveolar bone width in the posterior mandible was significantly greater across all facial patterns. This indicated that sagittal volume orientation can meaningfully alter the quantification of alveolar dimensions, with potential implications for implant planning. Similarly, Ardalani et al.[1] demonstrated that variations in head orientation specifically changes between occlusal-plane and mandibular-plane alignment can significantly affect CBCT-derived linear measurements of mandibular bone height and width, although previous studies have reported contradictory results regarding which parameters are most affected. The persistence of inconsistent findings across the literature, combined with methodological limitations noted in earlier studies, underscores the absence of a clear consensus on how sagittal orientation influences morphometric CBCT measurements [15]. This inconsistency points to the need for controlled investigations addressing this issue with greater precision. Despite the relevance of this topic, only study of Costa et al.[6] has specifically assessed the influence of sagittal volume orientation on alveolar bone width in the posterior mandible, and that study evaluated only two orientation angles and included a relatively small mesofacial sample. Considering that even minor variations in sagittal volume angulation may influence the perceived alveolar width in CBCT cross-sections, especially in implant site assessments, further research is warranted to determine the extent of this effect. Therefore, the present study aimed to investigate the impact of different sagittal volume orientation angles on the measurement of alveolar bone width in the posterior mandible of individuals with a normal facial pattern (mesofacial).

MATERIALS AND METHODS

Study design, ethical approval and sample selection

This cross-sectional retrospective study was conducted on CBCT scans obtained from the Department of Oral and Maxillofacial Radiology at Tabriz University of Medical Sciences, following approval from the institutional Ethics Committee (IR.TBZMED.REC.1402.012). A total of 165 scans from 165 individuals aged 23–52 years were included. Scan selection followed strict criteria: full maxillofacial field of view, absence of motion or metallic artifacts, patient age over 20 years, and the presence of both first and second right mandibular molars. Cases with bone pathology, fractures, skeletal asymmetry, severe dental crowding impairing occlusal plane identification, or brachyfacial/dolichofacial patterns were excluded. Facial pattern was verified using the Frankfort–Mandibular Plane Angle (FMA), and only mesofacial cases with FMA = 25 ± 5° were included [16,17]. Sample size was determined with G*Power using a pilot dataset, resulting in a required minimum of 157 scans; therefore, 165 were analyzed.

CBCT acquisition, reconstruction, and volume standardization

All images were obtained with a NewTom VGi scanner (Verona, Italy), using a cone-shaped beam and a flat-panel detector (1536 × 1920 pixels). Acquisition parameters included 360° rotation, 18-second exposure time, and an automatic exposure system with up to 110 kVp and 1–20 mA. Images were reconstructed and evaluated using NNT Viewer version 8.0.0.

Prior to generating sagittal slices, the CBCT volumes were standardized across three planes. In the coronal plane, the horizontal axis was aligned parallel to the inter-gonial line. In the axial plane, the anteroposterior reference was aligned parallel to the ANS–PNS line **(Fig. 1**). A reconstructed lateral cephalogram was generated by drawing a horizontal line between the posterior borders of both condyles on the axial view, producing sagittal slices perpendicular to that reference (**Fig. 2**, A). Slice thickness and width were set to 150 mm and 250 mm, respectively.

Sagittal orientation protocol, occlusal plane definition, and measurement procedure.

Seven sagittal reconstruction angles were generated for each scan relative to the Bisected Occlusal Plane (BOP):

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OP (0°), OP + 5°, OP + 10°, OP + 15°, OP + 20°, OP + 25°, and OP + 30°. Throughout these orientations, axial and coronal planes remained constant to avoid introducing unintended dimensional distortion. The BOP was defined as the line connecting the midpoint between the maxillary–mandibular first molars and the midpoint between the maxillary–mandibular central incisors [15] (**Fig. 3**), ensuring stable reference positioning even when maximum intercuspation was not achieved. For each orientation, a panoramic curve was drawn manually along the mandibular ridge on the axial plane (Fig. 2, B), producing a panoramic reconstruction and corresponding cross-sectional slices. The slice intersecting the midpoint between the first and second right mandibular molars was selected for analysis. Alveolar bone width was measured as the perpendicular distance between the buccal and lingual cortical plates at the widest region of the alveolar ridge (**Fig. 4**).

Statistical Analysis

Data were reported as Mean ± standard deviation for quantitative variables and qualitative variables were presented as frequency and percentage. Shapiro-wilk test was used to assess the data distribution. In case of normal data, Independent T test was used to compare means between two groups, while Mann-Whitney U was used in case data were not normally distributed.

Repeated measure ANOVA was used to assed the differences across seven reconstruction angles. Data were analyzed using SPSS v.26 and P value less than 0.05 was considered statistically significant. Intra-observer reliability was evaluated by repeating measurements on 30 randomly selected scans after a two week interval under blinded conditions. Intraclass Correlation Coefficients (ICC) were calculated using a two way random effects model with absolute agreement, and interpreted according to the guidelines of Koo and Li [18].

RESULTS

A total of 165 CBCT scans were evaluated, comprising 89 images from women and 76 from men, with a mean age of 37.4 ± 7.6 years (range: 23–52 years). Intra-observer reliability demonstrated excellent repeatability across all seven sagittal orientations. The Intraclass Correlation Coefficients (ICC) for alveolar bone width measurements ranged from 0.997 to 0.998, with narrow 95% confidence intervals (0.994–0.999) and $p < 0.001$ for all angles, confirming the high internal consistency of the measurement protocol.

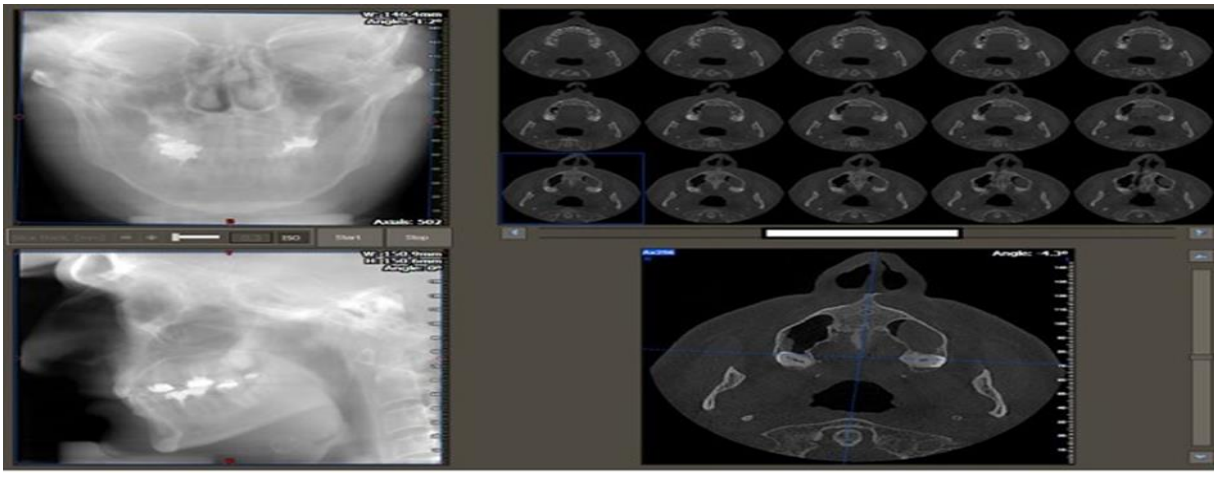

Figure 1. Correction of head deviations in CBCT volume to create a reformatted lateral cephalogram.

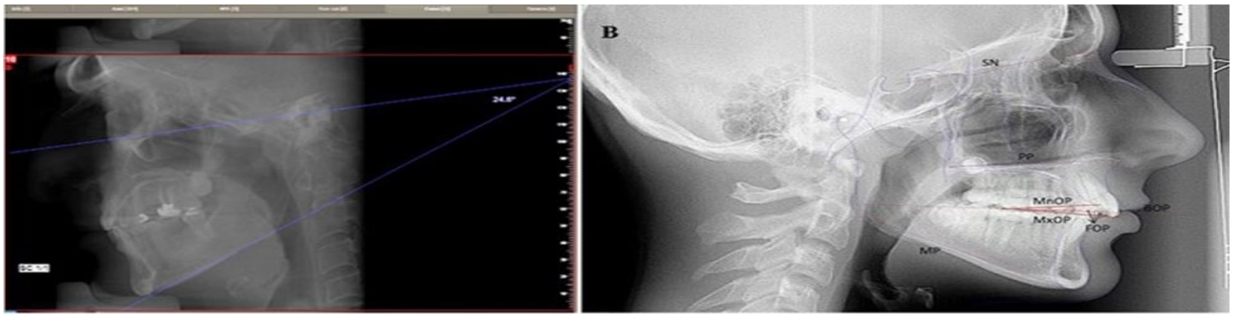

Figure 2. A) Reformatted lateral cephalogram showing the measurement of the Frankfort–Mandibular Plane Angle (FMA) in a mesofacial subject. B) Different definitions of the occlusal plane. The bisected occlusal plane (BOP)—marked with an orange line—was adopted as the reference OP in the settings.

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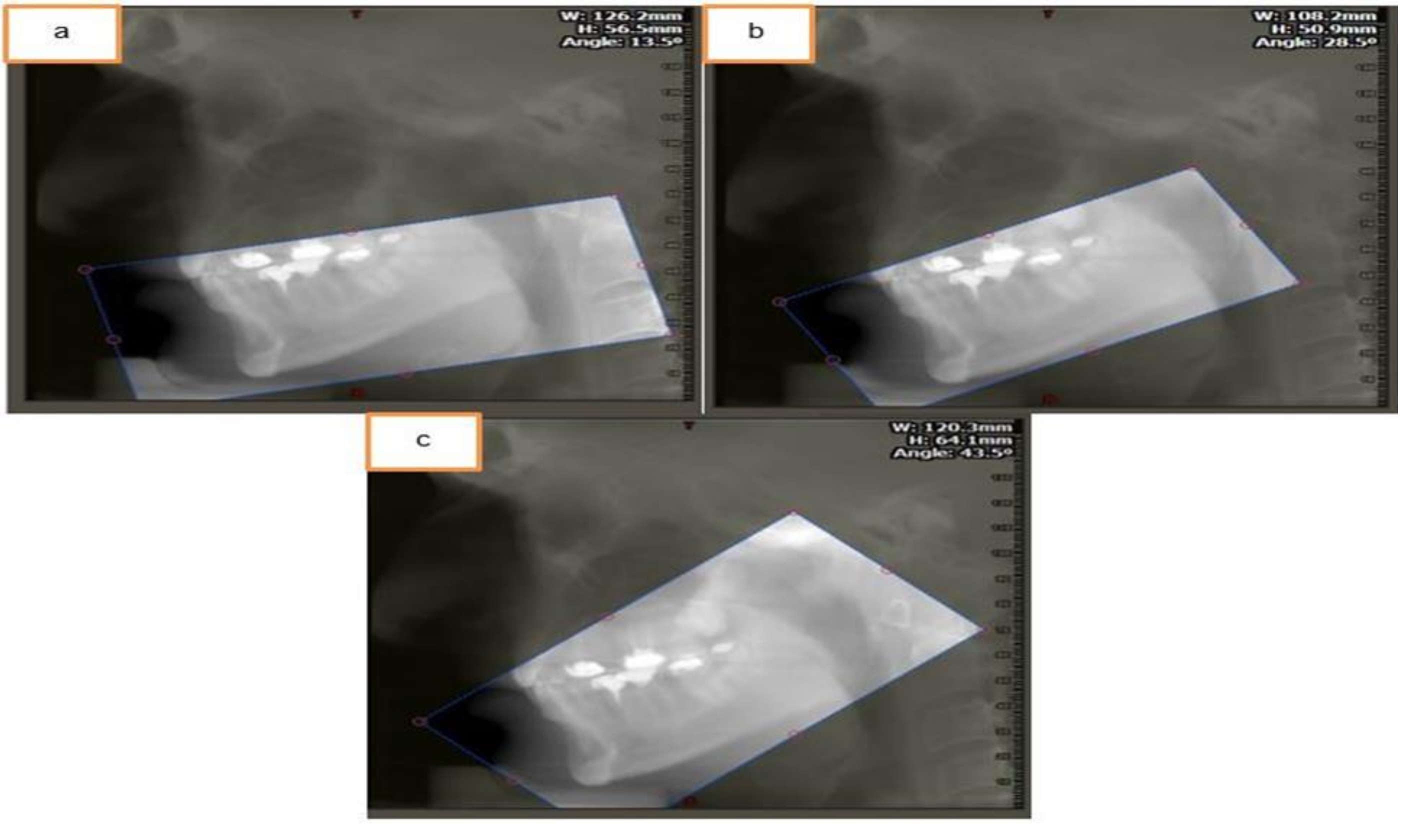

Figure 3. Sagittal volume orientation at different reconstruction angles. a) Parallel to the occlusal plane (OP). b) OP +15°. c) OP +30°.

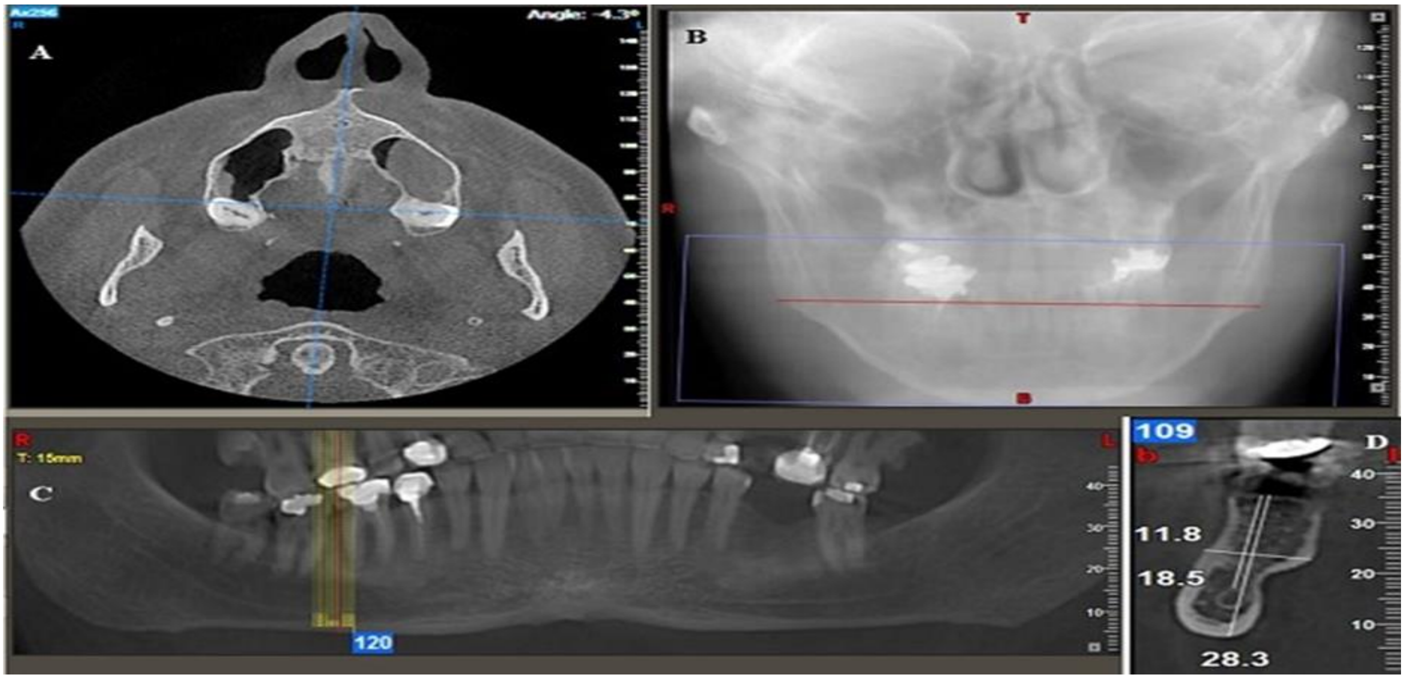

Figure 4. Neutral alignment of CBCT volume orientation in axial (A) and coronal planes (B). C) Selection of the cross-sectional slice at the interradicular region between the first and second mandibular molars. D) Measurement of alveolar bone width in the posterior mandible between the buccal and lingual cortical plates.

Across the seven sagittal orientations, alveolar bone width increased progressively as the CBCT volume was tilted relative to the Bisected Occlusal Plane (**Fig. 5**). At the OP (0°) position, the mean width measured 11.18 ± 1.60 mm, increasing to 11.48 ± 1.58 mm at OP+5° and 11.74 ± 1.59 mm at OP+10°. A further increase was observed at OP+15°, where the width reached 12.00 ±1.59 mm, a value identical to that recorded at OP+20° (12.00 ± 1.59 mm). Minor fluctuations were noted at higher inclinations, with the width measuring 11.98 ± 1.57 mm at OP+25° and reaching its maximum at OP+30° (12.07 ± 1.58 mm). According to the repeated measures ANOVA, these differences across sagittal orientations were statistically significant ($p < 0.001$). Pairwise Bonferroni comparisons demonstrated a consistent increase in alveolar bone width with greater sagittal inclination (**Table 1**). Measurements at OP (0°) were significantly smaller than those obtained at all other orientations from OP+5° through OP+30° ($p < 0.001$). Likewise, OP+5° was significantly smaller than OP+10° to OP+30° ($p < 0.001$), and OP+10° remained significantly smaller than OP+15° to OP+30° ($p < 0.001$). No significant differences were observed among OP+15°, OP+20°, and OP+25° ($p = 1.000$). In contrast, OP+30° yielded significantly greater widths compared to OP+15° ($p = 0.005$), OP+20° ($p = 0.021$), and OP+25° ($p < 0.001$).

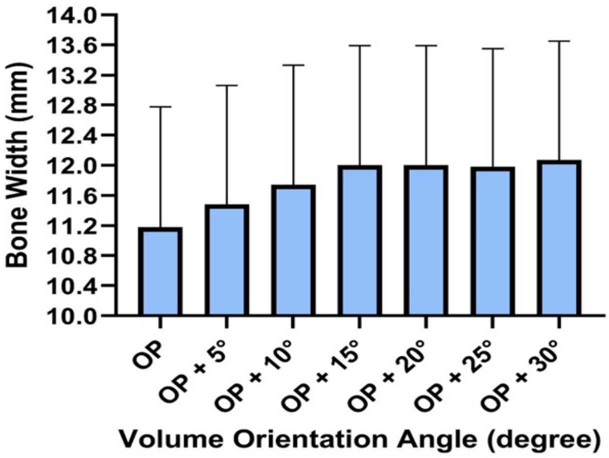

Figure 5. Comparison of alveolar bone width measurements at different sagittal reconstruction angles (0° to +30°). OP: Occlusal Plan

Table 1. Bonferroni pairwise comparisons of alveolar bone width between sagittal orientation angles

Angle (I)	Angle (J)	Mean difference (I-J)	Standard error	P value
OP	OP + 5	-0.31	0.006	< 0.001
	OP + 10	-0.56	0.018	< 0.001
	OP + 15	-0.82	0.016	< 0.001
	OP + 20	-0.82	0.019	< 0.001
	OP + 25	-0.80	0.022	< 0.001
	OP + 30	-0.89	0.024	< 0.001
OP + 5	OP + 10	-0.26	0.017	< 0.001
	OP + 15	-0.52	0.016	< 0.001
	OP + 20	-0.52	0.018	< 0.001
	OP + 25	-0.50	0.021	< 0.001
	OP + 30	-0.59	0.023	< 0.001
OP + 10	OP + 15	-0.26	0.011	< 0.001
	OP + 20	-0.26	0.016	< 0.001
	OP + 25	-0.24	0.019	< 0.001
	OP + 30	-0.33	0.021	< 0.001
OP + 15	OP + 20	0.002	0.011	1
	OP + 25	0.019	0.016	1
	OP + 30	-0.07	0.018	0.005
OP + 20	OP + 25	0.02	0.015	1
	OP + 30	-0.07	0.0.21	0.021
OP + 25	OP + 30	-0.09	0.015	< 0.001

OP: Occlusal Plane

DISCUSSION

This study evaluated the impact of sagittal CBCT volume orientation on alveolar bone width in the posterior mandible of mesofacial individuals. Accurate assessment of alveolar bone width and height is fundamental for implant therapy success, as it directly guides implant diameter selection, surgical approach, and the avoidance of vital structures [7,19,20]. CBCT, recommended by the American Academy of Oral and Maxillofacial Radiology as the preferred modality for implant site assessment due to its volumetric data and dimensional accuracy [11, 12, 19, 21], remains sensitive to various technical and operator dependent factors including head and volume orientation which may influence the true anatomical correspondence of reconstructed cross-sections.

In the present study, increasing sagittal reconstruction angle from the occlusal plane (OP) to +15° produced a consistent increase in measured alveolar width. This agrees with Costa et al. [22], who also found wider alveolar dimensions when the CBCT volume was oriented parallel to the mandibular base rather than the occlusal plane. The geometric explanation is well demonstrated in their trigonometric model, showing that only one shortest distance exists between two points, while tilting the volume produces an infinite number of longer measurements proportional to the cosine of the inclination angle; thus, overestimation is more likely than underestimation [22]. As the angle increases, the cross-sectional slice shifts posteriorly toward thicker regions of the mandibular body, explaining the progressive width increase observed in both our study and previous work [22]. Beyond +15°, however, further increase in angle produced minimal change, indicating a saturation effect with no meaningful clinical impact. These findings indicate that the effect of head orientation on linear accuracy depends on anatomical location, reconstruction axis, and whether scans are acquired in vivo or in vitro.

Although CBCT linear errors typically range between 0.4 and 0.6 mm [23, 24], even modest deviations near 1 mm may influence treatment decisions, especially in the posterior mandible where bone thickness is limited. In our study, the maximum observed difference (~0.9 mm) falls within clinically significant thresholds, reinforcing the need for accurate volume orientation when planning implant placement. Similar findings regarding clinically relevant deviations were reported by Ardalani et al., who noted that occlusal-plane alignment consistently produced measurements closest to the gold standard across most mandibular sites, except in posterior regions where head orientation exerted minimal influence [1, 25]. Other studies further support the necessity of standardizing orientation, showing that tilting, rotation, or modifying slice angulation can produce small but systematic deviations in linear dimensions [20, 21, 26-28].

Intra-observer reliability was excellent, confirming that measurement variation reflected genuine geometric changes rather than observer inconsistency, similar to the high reproducibility reported in earlier CBCT studies [1, 22]. Several methodological considerations must be acknowledged. All scans were acquired using a single CBCT system (NewTom VGi) and a specific reconstruction platform, which may limit generalizability since device specifications, voxel size, and filtering algorithms can influence measurements. The sample included only mesofacial individuals, although previous studies indicate that dolichofacial subjects with greater gonial angles and retrognathic mandibles may show different dimensional behaviors [26, 27]. In addition, variables such as tooth loss timing, soft-tissue variations, or minor anatomical irregularities were not controlled, although healed sockets reduce susceptibility to post-extraction dimensional change [28]. These limitations mirror those noted in prior CBCT studies and emphasize the need for multi-device, multi-operator, and multi-profile investigations.

CONCLUSION

This study demonstrated that modifying the sagittal reconstruction angle of CBCT volumes has a meaningful impact on the measurement of alveolar bone width in the posterior mandible. Increasing the sagittal orientation from parallel to the occlusal plane toward the mandibular plane resulted in a progressive and statistically significant increase in the measured ridge width across all evaluated angles. The mean difference between the reference orientation (OP) and OP+15° was approximately 0.8–0.9 mm an increment that falls within the range considered clinically relevant for implant planning. This systematic increase can be attributed to the posterior displacement of the cross sectional plane as the volume is rotated, causing measurements to pass through anatomically wider regions of the mandibular body.

Given these findings, precise control of sagittal volume orientation during CBCT reconstruction is essential to maintain measurement accuracy and avoid inadvertent overestimation of bone dimensions. In clinical practice, implementing a tolerance margin of approximately ±0.5 mm when interpreting ridge width measurements may help mitigate potential errors, particularly in regions where surgical safety margins are critical. Standardizing CBCT orientation protocols is therefore strongly recommended to enhance diagnostic reliability and support optimal implant site assessment.

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Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Farshad Bagheri and Sedigheh Razi contributed to the study conception and design. Material preparation, data collection and analysis were performed by Farshad Bagheri, Tahmineh Razi, Kasra Rahimipour and Ehsan Yousefian. The first draft of the manuscript was written by Farshad Bagheri and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript

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Ethics approval
The setting of this study has been approved by the Ethics Committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.1402.012).

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