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Effect of head orientation on mandibular bone linear measurements in CBCT imaging

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Abstract

Objective Cone Beam Computed Tomography (CBCT) is a widely used diagnostic tool for bone assessment. However, the impact of head orientation on linear bone measurements remains debated. This study aimed to evaluate whether the occlusal plane or the mandibular plane orientation provides more accurate measurements of mandibular height and width compared to a standard reference.

Materials and methods Five dry human mandibles were imaged at the Faculty of Dentistry, Islamic Azad University, Khorasgan, in 2024. CBCT scans were obtained using a NewTom VGi evo device. The scans were exported as DICOM and analyzed in ONDEMAND software. Measurements were taken in two head orientations: (1) occlusal plane parallel to the horizon and (2) mandibular plane parallel to the horizon. Mandibular height was measured from the alveolar crest to the inferior border at the incisor, canine, premolar, and molar sites. Bone width was measured from the buccal to the lingual cortical plate at the same sites. The measurement locations were pre-marked with gutta-percha to ensure consistency. The CBCT-derived measurements were then compared to caliper measurements.

Results Results indicated that measurements with the occlusal plane aligned to the horizon were generally closer to standard values compared to those with the mandibular plane aligned to the horizon. Statistically significant differences were observed in bone height at the canine site: mandibular plane (26.50 mm) vs. occlusal plane (26.99 mm) ($p = 0.004$), and both planes showed significant differences compared to the caliper measurement (27.78 mm) ($p = 0.005$ for mandibular plane, $p = 0.018$ for occlusal plane). At the premolar site, significant differences observed between the caliper measurement (28.57 mm) and both planes (mandibular plane: 27.36 mm, $p < 0.001$; occlusal plane: 27.62 mm, $p = 0.01$). In bone width at the canine site, both planes showed significant differences ($p = 0.047$). No significant differences were found at the molar site.

Conclusion This study suggests that aligning the occlusal plane to the horizon results in more accurate CBCT-derived linear measurements of mandibular height and width compared to the mandibular plane orientation. Therefore, the occlusal plane may be the preferred reference for CBCT-based bone measurements.

Keywords Cone beam computed tomography, Head orientation, Mandibular plane, Occlusal plane, Bone height, Bone width

Introduction

The utilization of dental implants has expanded significantly in recent decades, providing effective solutions for previously challenging clinical cases. Given their widespread application, accurate preoperative assessment of ridge morphology, including bone height and width, is essential to ensure precise implant placement and avoid complications related to vital structures.

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Cone-beam computed tomography (CBCT) has become the preferred imaging modality for implant dentistry due to its three-dimensional capabilities and lower radiation dose compared to conventional CT scans [1, 2]. CBCT is widely recognized as a reliable tool for diagnosis and treatment planning [3]. However, despite its advantages, studies have reported discrepancies in CBCT-derived linear measurements of the ridge, with recorded dimensions sometimes deviating from actual bone size [3]. Underestimation of ridge dimensions may result in shorter implants and compromised treatment outcomes, while overestimation poses risks of interference with vital structures. It is important to note that most of these discrepancies arise from operator-dependent factors, such as measurement technique, head positioning, and human error, rather than inherent limitations of CBCT technology [3].

Several factors contribute to these measurement discrepancies, including CBCT device specifications, software algorithms, patient movement during scanning, and errors in automated or manual processing [3, 4]. One aspect that has received increasing attention is head orientation during CBCT acquisition, as the positioning of the patient's head may influence measurement accuracy.

In cone-beam computed tomography (CBCT) studies, head orientation significantly influences the accuracy of linear measurements, particularly those assessing alveolar ridge bone height and width. Standardizing head positioning is crucial for ensuring consistent and reproducible measurements in morphometric analyses. The occlusal plane, often used as a reference in dental imaging, is typically defined by the alignment of the teeth, extending from the anterior incisors to the posterior molars. However, in edentulous patients or studies involving dry mandibles, where no teeth are present, the occlusal plane becomes difficult to define and is instead based on anatomical landmarks. In these cases, the mandibular plane defined by the line connecting the Gonion and Menton provides a reliable alternative for establishing head orientation [5, 6].

Existing studies on this subject have reported conflicting findings. Some have found no statistically significant differences in measurements obtained with different head orientations, including tilt [7, 8] and rotation [7, 9, 10], compared to standard positioning. In contrast, other studies have identified significant differences depending on head orientation [11]. Additionally, research assessing alveolar bone dimensions has yielded mixed results: some studies reported significant variations in bone width but not height [5], while others found differences in bone height but not width [12, 13], and a few observed discrepancies in both parameters [14].

Although this subject may appear to be a straightforward matter, the absence of a conclusive resolution despite numerous studies underscores the necessity for further investigation. The necessity of patient positioning in every CBCT scan utilized for linear bone measurements further emphasizes the clinical significance of this topic. Precise and standardized positioning is imperative for obtaining reliable measurements, which directly influences treatment planning and outcomes in implant dentistry.

This study aims to evaluate the impact of head orientation—specifically aligning either the occlusal plane or the mandibular plane parallel to the horizon—on CBCT-derived measurements of mandibular bone height and width. Despite multiple studies addressing similar topics, the literature presents paradoxical results, lacking a clear consensus. Previous studies have investigated the influence of head orientation on CBCT-based measurements; however, many have methodological limitations. A common issue is the lack of a valid reference point for consistent measurements, leading to potential variability. Additionally, only a few studies have divided the mandible into distinct zones for analysis, limiting the understanding of how different regions may be affected by orientation changes. Furthermore, measurement accuracy can vary depending on the methodological approach used, leading to inconsistencies in the results. Our study addresses these gaps by defining a valid reference point, systematically analyzing different mandibular zones, using best settings in software and ensuring a consistent and reproducible methodology.

By accounting for all relevant factors that could influence this controversial topic, we aim to provide a more comprehensive understanding and contribute to resolving uncertainties in this field. Our findings may help establish a stronger consensus and enhance clinical decision-making in implant dentistry.

Materials and methods

Study design and ethical approval

This descriptive and analytical study was approved by the Ethics Committee of the Islamic Azad University, Isfahan (Khorasgan) Branch, under the ethics code IR.IAU.KHUISF.REC.1403.079. The study adhered to all ethical guidelines and international standards for the use of cadaveric material in research.

The required sample size for each group was calculated to be 5, based on a two-tailed test with a significance level of 0.05 and statistical power of 80%, considering a 180% difference in standard deviation.

Five dry human mandibles were selected from the Faculty of Dentistry, Islamic Azad University, Khorasgan Branch, for imaging. The mandibles were selected based

on the inclusion criteria outlined below. The study was conducted in 2024, and all mandibles were inspected for suitability before inclusion in the analysis.

Inclusion and exclusion criteria

Inclusion criteria:

- Intact human dentate or edentulous mandibles suitable for CBCT imaging
- Detectable occlusion and mandibular plane

Exclusion criteria:

- Presence of fractures in the mandible
- Loss of any occlusal or mandibular planes
- Mandibles with severe resorption
- Mandibles with severe deformities

Measurements references

Before selecting the final measurement method, a pilot study was conducted to determine the most reliable and reproducible reference points for CBCT analysis. Several reference points were evaluated for consistency using the Intraclass Correlation Coefficient (ICC) based on repeated measurements by multiple observers. The reference points with the highest ICC values were chosen for the main study to ensure optimal reproducibility and minimize observer variability. This preliminary validation strengthened the reliability of the CBCT measurement methodology used in this study.

Width: The width was measured from the most buccal edge to the most lingual edge of the gutta-percha marking.

Height: The height was measured from the most apical point of the gutta-percha on the ridge to the most coronal point of the gutta-percha on the mandibular border.

These reference points was used for both direct measurement with caliper and CBCT measurements.

The occlusal plane: often used as a reference in dental imaging, is typically defined by the alignment of the teeth, extending from the anterior incisors to the posterior molars. However, in edentulous patients or studies involving dry mandibles, where no teeth are present, the occlusal plane becomes difficult to define and is instead based on anatomical landmarks.

The mandibular plane: defined by the line connecting the Gonion and Menton provides a reliable alternative for establishing head orientation.

Direct measurements (Caliper on dry mandible)

Prior to imaging, specific anatomical landmarks were marked with 2% gutta-percha size 30 (Raiffeisenstraße 30, 89,129 Langenau, Germany, Coltene) at the molar, premolar, canine, and incisor sites to facilitate precise height and width measurements within the software. Vertical distances and desired widths were also measured using a calibrated caliper (Mituyoto, Japan) as reference values for comparison (Fig. 1).

CBCT imaging protocol and analysis

The CBCT images were obtained using a NewTom VGi evo CBCT unit (110 kVp, 3 mA, with a voxel size of 0.1 mm^3 and an 8× 12 cm FOV) at faculty of Dentistry, Islamic Azad university,Khorasgan. The mandibles were mounted and fixed on the CBCT device using impression material to maintain alignment during imaging. Each mandible underwent two separate CBCT exposures (Fig. 2).

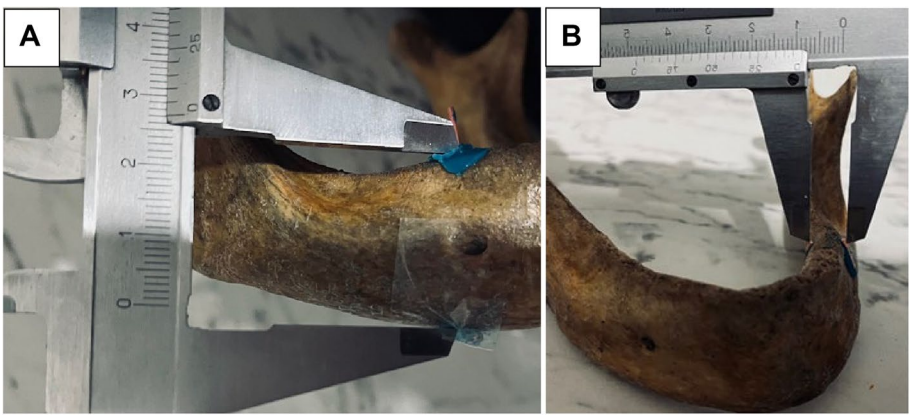

Fig. 1 Direct Measurements of (**A**) Height and (**B**) width by Caliper on dry mandible

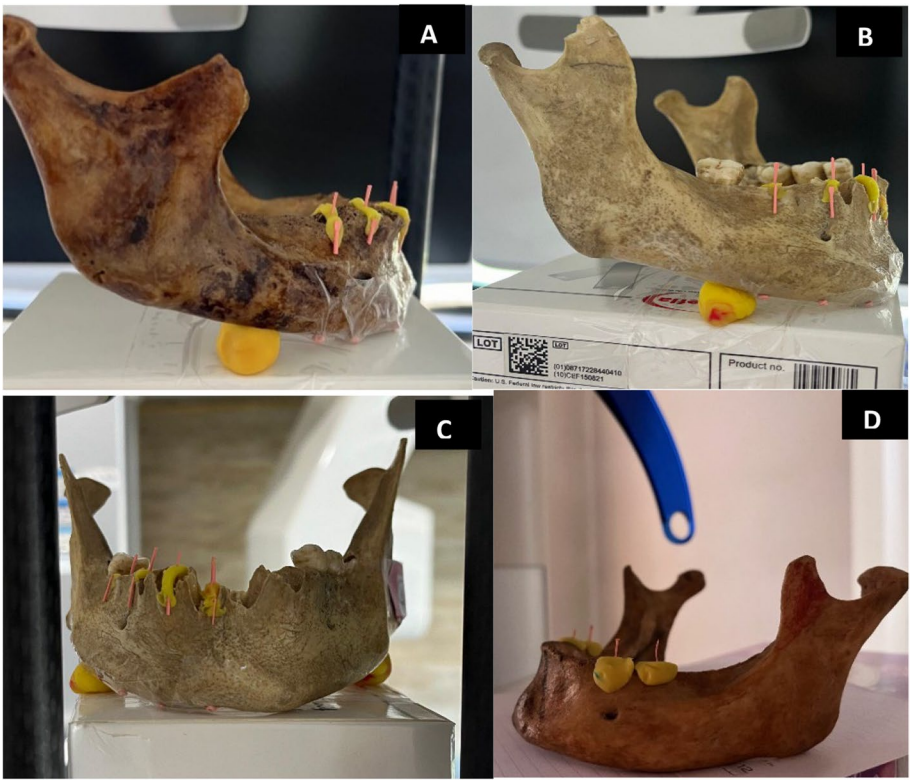

Fig. 2 Aligning the Occlusal plane of dry mandibles parallel to horizon in CBCT Machine (**A**-**C**). And Aligning the mandibular plane parallel to horizon (**D**)

1. The first exposure was made with the occlusal plane aligned parallel to the horizontal plane.
2. The second exposure was made with the mandibular plane aligned parallel to the horizontal plane [15, 16].

The acquired CBCT data were exported in DICOM format and analyzed using ONDEMAND 3D Dental software (Cybermed Inc, Seoul, Korea) (Fig. 3). In the software's 3D menu, a slice thickness of 1 mm and a filter setting of 1.5 were applied. These parameters were selected to optimize the image quality for accurate measurements (Figs. 4 and 5). Measurements were performed by two evaluators: one expert oral and maxillofacial radiologist and one oral and maxillofacial radiology resident and average registered for each sample.

Statistical analysis

Statistical analysis was performed using SPSS software version 26, with parametric tests chosen for the sample

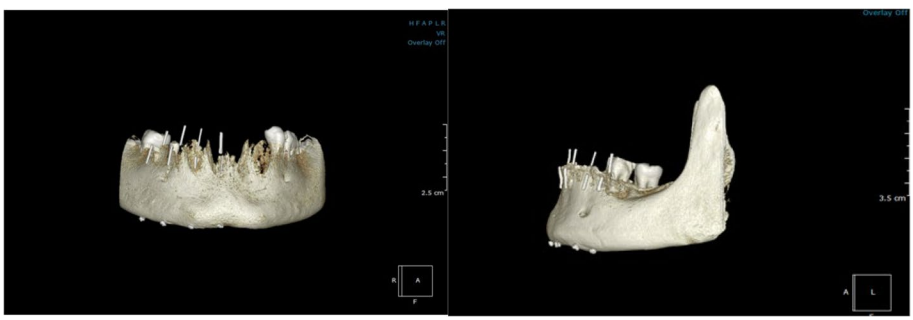

Fig. 3 3D Model of the Mandible Exposed with the Mandibular Plane Parallel to the Horizon. (ONDEMAND software)

Fig. 4 The ONDEMAND software environment in the 3D menu

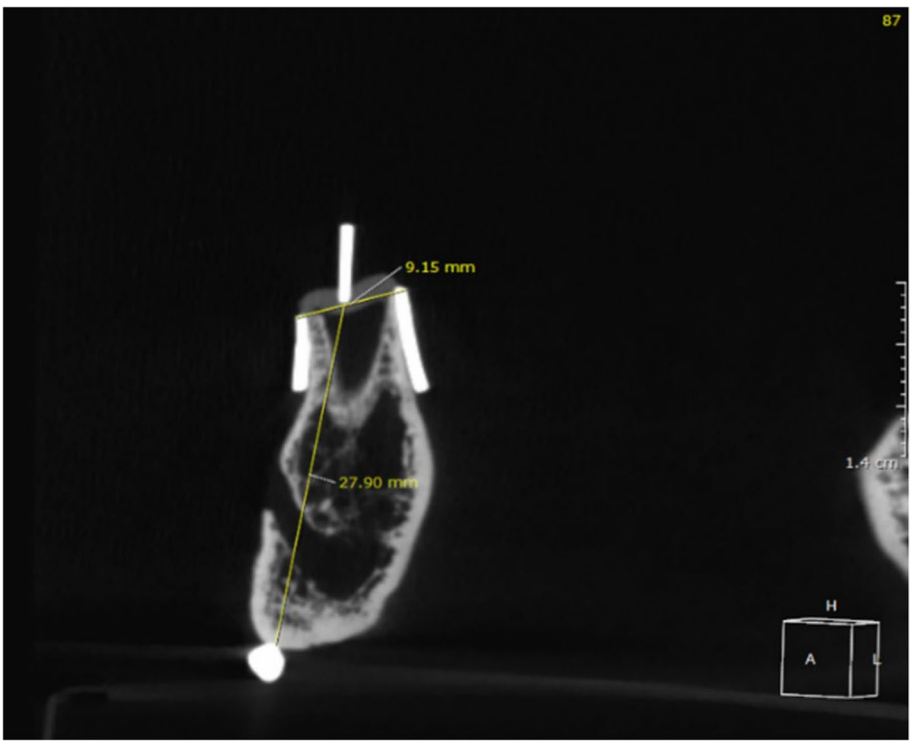

Fig. 5 Cross Sectional view of Measuring Bone Height and Width (pilot). Note the Markings Made with Gutta-Percha

size of five mandibles. A significance level of 0.05 was applied. Descriptive analysis was performed using frequency distribution tables and relevant graphs, while inferential analysis employed parametric tests with a significance level of 0.05. The paired Student's t-test was used for comparing the measurements derived from the

CBCT images and the true values obtained from dry skulls using a calibrated caliper.

Intraobserver and interobserver reliability

Intraobserver and interobserver reliability were assessed by having two observers perform measurements on the mandibles twice, with a two-week interval between sessions. The reliability of the measurements was evaluated using the Intraclass Correlation Coefficient (ICC).

Results

Descriptive statistics and comparison of measurements

The measurements of bone height and width at the four sites (central tooth area, canine site, premolar site, and molar site) were analyzed for two alignment conditions: occlusal plane aligned to the horizon and mandibular plane aligned to the horizon. For each site, both descriptive statistics (mean, standard deviation) and inferential statistics (paired t-test) were performed.

The study evaluated the impact of head orientation on linear measurements of bone height and width at four anatomical sites: central incisor, canine, premolar, and molar. Measurements were assessed using two reference planes: the mandibular plane and the occlusal plane, and were compared to measurement obtained with a caliper.

Bone height measurements

As Table 1 presents.

The effect of head orientation on bone height measurements varied across different anatomical sites. Overall, the occlusal plane-aligned measurements were closer to the caliper reference values, suggesting that this alignment might be more accurate.

At the central incisor site, although measurements from both planes differed significantly from the caliper reference, the occlusal plane-aligned values were slightly more accurate. A similar trend was observed at the canine and premolar sites, where statistically significant differences were found between the two alignment conditions. The occlusal plane yielded values that were more comparable to the caliper measurements, reinforcing its potential advantage.

In contrast, at the molar site, no statistically significant differences were found between the two alignments or between the caliper and CBCT measurements. This suggests that at posterior regions, head orientation may have less impact on measurement accuracy.

The details of these differences are presented in the following sections:

Central incisor site

The mean bone height was 26.34 mm for the mandibular plane and 27.06 mm for the occlusal plane.

Table 1 Descriptive statistics of bone height at various sites: comparison between occlusal and mandibular planes

Measurement Site	Plane Alignment	Mean ± SD (mm)	*P* Value*
Central incisor Site	Occlusal Plane	27.06 ± 4.33	0.040
	Mandibular Plane	26.34 ± 4.15	0.047
	Measurement with Caliper	27.62 ± 4.44	-
Canine Site	Occlusal Plane	26.99 ± 4.79	0.018
	Mandibular Plane	26.50 ± 4.64	0.005
	Measurement with Caliper	27.78 ± 4.69	-
Premolar Site	Occlusal Plane	27.62 ± 3.87	0.010
	Mandibular Plane	27.36 ± 3.87	< 0.001
	Measurement with Caliper	28.57 ± 3.87	-
Molar Site	Occlusal Plane	26.05 ± 4.05	0.126
	Mandibular Plane	25.73 ± 3.72	0.088
	Measurement with Caliper	26.69 ± 4.48	-

* T-test in comparison with measurement with caliper

The occlusal plane measurement was closer to the caliper measurement (27.62 mm).

Statistical analysis

No significant difference between the mandibular and occlusal planes ($p = 0.093$).

Significant differences between both planes and the caliper measurement ($p = 0.047$ for the mandibular plane, $p = 0.040$ for the occlusal plane).

Canine site

Mean bone heights: 26.50 mm (mandibular plane), 26.99 mm (occlusal plane), and 27.78 mm (Caliper measurement).

Statistical analysis

Significant difference between the mandibular and occlusal planes ($p = 0.004$).

Significant differences between both planes and the Caliper measurement ($p = 0.005$ for the mandibular plane, $p = 0.018$ for the occlusal plane).

Premolar site

Mean bone heights: 27.36 mm (mandibular plane), 27.62 mm (occlusal plane), and caliper measurement was significantly different.

Statistical analysis

No significant difference between the mandibular and occlusal planes ($p = 0.258$).

Significant differences between both planes and the caliper measurement ($p < 0.001$ for the mandibular plane, $p = 0.010$ for the occlusal plane).

Molar site

Mean bone heights: 25.73 mm (mandibular plane), 26.05 mm (occlusal plane), and closer to the caliper measurement.

Statistical analysis

No significant difference between the mandibular and occlusal planes ($p = 0.352$).

No significant difference between both planes and the caliper measurement ($p > 0.05$).

Across all sites, the occlusal plane showed values closer to the caliper measurement. However, statistical significance varied, with notable differences observed at the canine and premolar sites, while no significant differences were found at the molar site.

Bone width measurements

As Table 2 presents

Similar to the height measurements, the occlusal plane generally resulted in width measurements closer to the caliper reference. The most notable differences were observed at the canine and premolar sites, where measurements between the two alignments were statistically different. However, for the molar and premolar sites, no significant differences were found between either CBCT measurement and the caliper values, indicating relatively consistent measurements regardless of alignment.

Table 2 Descriptive statistics and inferential analysis of bone width at various sites: comparison between occlusal and mandibular planes

Measurement Site	Plane Alignment	Mean ± SD (mm)	*P* Value*
Central incisor Site	Occlusal Plane	4.50 ± 1.26	0.025
	Mandibular Plane	4.34 ± 1.29	0.049
	Measurement with Caliper	5.08 ± 1.32	-
Canine Site	Occlusal Plane	6.45 ± 1.27	0.047
	Mandibular Plane	6.28 ± 1.42	0.047
	Measurement with Caliper	6.85 ± 1.15	-
Premolar Site	Occlusal Plane	6.60 ± 0.94	0.165
	Mandibular Plane	6.21 ± 1.21	0.078
	Measurement with Caliper	6.87 ± 0.98	-
Molar Site	Occlusal Plane	8.25 ± 2.21	0.420
	Mandibular Plane	7.78 ± 2.13	0.095
	Measurement with Caliper	8.38 ± 2.00	-

* T-test in comparison with measurement with caliper

Overall, the findings highlight that head positioning can influence the accuracy of linear bone measurements, particularly in anterior regions. The occlusal plane alignment appears to provide more reliable results, whereas the mandibular plane alignment may introduce small but significant discrepancies in specific regions. These findings underscore the importance of standardizing head positioning in both research and clinical CBCT assessments.

The details of these differences are presented in the following sections:

Central incisor site

Mean bone widths: 4.34 mm (mandibular plane), 4.50 mm (occlusal plane), and closer to the caliper measurement.

Statistical analysis

No significant difference between the mandibular and occlusal planes ($p = 0.366$).

Significant differences between both planes and the standard measurement ($p = 0.049$ for the mandibular plane, $p = 0.025$ for the occlusal plane).

Canine site

Mean bone widths: 6.28 mm (mandibular plane), 6.45 mm (occlusal plane), and closer to the caliper measurement.

Statistical analysis

No significant difference between the mandibular and occlusal planes ($p = 0.226$).

Significant differences between both planes and the caliper measurement ($p = 0.047$ for both).

Premolar site

Mean bone widths: 6.21 mm (mandibular plane), 6.60 mm (occlusal plane), and closer to the caliper measurement.

Statistical analysis:

Significant difference between the mandibular and occlusal planes ($p = 0.047$).

No significant difference between either plane and the caliper measurement ($p > 0.05$).

Molar site

Mean bone widths: 7.87 mm (mandibular plane), 8.25 mm (occlusal plane), and closer to the caliper measurement.

Statistical analysis

Significant difference between the mandibular and occlusal planes ($p = 0.048$).

No significant difference between either plane and the caliper measurement ($p > 0.05$).

The occlusal plane values were generally closer to the caliper measurements. Significant differences were observed between the mandibular and occlusal planes at the premolar and molar sites, while no significant differences were found between the occlusal plane and the caliper measurement at most sites.

The occlusal plane generally provided measurements closer to the caliper measurement for both bone height and width. However, statistical significance varied across sites, with the canine and premolar regions showing more pronounced differences. No significant differences were found at the molar site for either height or width. These findings highlight the influence of head orientation on linear measurements, which is crucial for improving measurement accuracy in clinical and research settings.

Agreement between observers (Reproducibility)

To evaluate the reproducibility of linear measurements of mandibular height and width, both inter- and intra-observer reliability were assessed using the intraclass correlation coefficient (ICC). The results demonstrated excellent reliability for both analyses. Inter-observer reliability for height and width measurements in order yielded an ICC value of 0.999 (95% CI: 0.998–1.000, $p < 0.001$) and 0.998 (95% CI: 0.997–1.000, $p < 0.001$), indicating near-perfect agreement between observers. Similarly, intra-observer reliability for height and width measurements in order showed an ICC value of 0.999 (95% CI: 0.997–1.000, $p < 0.001$) and 0.997 (95% CI: 0.996–1.000, $p < 0.001$), confirming the high consistency of repeated measurements by the same observer. These findings validate the robustness and reproducibility of the measurement process, ensuring the reliability of the collected data.

Discussion

With the advancement of reconstructive and dental replacement therapies, the need for imaging techniques that provide an accurate assessment of both the quality and quantity of bone has become more crucial, especially when evaluating implant sites, which directly impacts the success of treatments. Three-dimensional imaging techniques, such as CBCT, have demonstrated the ability to deliver higher levels of accuracy and reliability in measurements. The ability to maintain dimensional accuracy in any imaging method is critical, particularly when the patient's head deviates from the ideal position during scanning.

In this study, we investigated the effects of the mandible orientation on the linear measurements of height and width of the mandibular bone using CBCT. Five human dry mandibles, each marked in four different regions, were scanned in two different positions: one where the occlusal plane was parallel to the horizon, and another where the mandibular plane was parallel to the horizon. Our findings revealed statistically significant differences and correlations between various variables in different analyses with results varying based on the measured site.

Regarding the differences between variables, descriptive analysis showed the means and standard deviations of bone measurements at the central incisor, canine, premolar, and molar locations across different planes (mandibular plane parallel to the horizon, occlusal plane parallel to the horizon, and the measurement with a caliper). The comparisons revealed that the occlusal plane parallel to the ground was closer to the caliper measurement, indicating higher accuracy in estimating the correct height and width of the bone.

The impact of head orientation on bone height measurements differed depending on the anatomical site. Measurements aligned with the occlusal plane generally showed closer agreement with caliper reference values, indicating higher accuracy compared to other alignments.

At the central incisor site, both alignment methods showed significant deviations from the caliper reference, though the occlusal plane-aligned measurements were marginally more precise. This pattern was also evident at the canine and premolar sites, where statistically significant differences were observed between the two alignment methods. The occlusal plane consistently produced values more aligned with the caliper measurements, suggesting its potential superiority.

In contrast, at the molar site, no statistically significant differences were detected between the two alignment methods or between CBCT and caliper measurements. This implies that head orientation may have a minimal effect on measurement accuracy in posterior regions.

For width measurements, the occlusal plane again demonstrated closer agreement with the caliper reference, particularly at the canine and premolar sites, where significant differences between alignment methods were noted. However, at the molar and premolar sites, CBCT measurements were consistent with the caliper values regardless of alignment, indicating stability in these regions.

In summary, head positioning plays a notable role in the accuracy of linear bone measurements, especially in anterior areas. The occlusal plane alignment tends to yield more reliable results, while the mandibular plane alignment may introduce minor but significant discrepancies in certain regions. These findings emphasize the need for standardized head positioning in both clinical and research applications of CBCT.

The results of this study emphasize the importance of aligning the occlusal plane parallel to the horizon in CBCT imaging, significantly improving the accuracy of linear measurements of bone height and width. This has important implications for surgical treatment planning and clinical decision-making [17].

Our findings indicate that aligning the occlusal plane parallel to the horizon enhances the accuracy of linear measurements of bone height and width, which aligns more closely with the gold standard in CBCT scans. This has considerable implications for clinical practice, particularly for procedures requiring precise anatomical measurements, such as implant placement, orthodontic treatment planning, and reconstructive and restorative surgeries [18].

Accurate patient positioning remains one of the most critical challenges for clinicians and radiographers in CBCT imaging. In routine practice, operators must ensure that the occlusal plane is positioned parallel to the horizon before exposure. For dentate patients, this is typically achieved by aligning the teeth; however, in edentulous patients, alternative anatomical landmarks must be used. We recommend establishing the occlusal plane based on reliable landmarks such as the retromolar pad, the commissure of the lips, and the residual ridge. Positioning aids like rods or bite blocks can further help stabilize the patient's head, reducing movement during scanning. These measures are essential to minimize operator-dependent errors and ensure that the CBCT measurements reflect true anatomical dimensions, ultimately improving clinical outcomes [19].

Despite the few statistically significant differences observed in our study, the clinical impact of these variations appears minimal. Clinically, a 1 mm difference is considered a cautionary distance when evaluating the proximity of vital structures. In our results, none of the differences reached or exceeded 1 mm—except for the height difference at the canine site and at the central site between the mandibular plane and the caliper measurement. This suggests that although statistical differences are present, they may not translate into clinically significant discrepancies, reinforcing the need for careful interpretation when applying these findings in clinical practice.

In dental implantology, accurate evaluation of bone dimensions is crucial for ensuring implant stability, minimizing the risk of nerve or sinus injury, and achieving optimal functional outcomes. Furthermore, in maxillofacial surgeries, such as mandibular reconstruction, the precision of CBCT measurements can substantially improve pre-surgical planning. Ensuring consistent and reliable measurements through appropriate occlusal plane alignment can assist surgeons in achieving superior functional and aesthetic post-surgical results. Similarly, orthodontists can leverage these findings to improve the accuracy of measurements for complex jaw alignment procedures, leading to better treatment outcomes [20].

Several studies have explored the relationship between occlusal plane alignment and the accuracy of CBCT measurements. Samy El Bachaoui and colleagues investigated the effect of head tilt in CBCT imaging on condylar image reconstruction [21]. They found that tilted head positions affected 3D condylar reconstruction but did not significantly impact clinical diagnoses or management. Our study contrasts with these findings, highlighting that aligning the occlusal plane parallel to the horizon improves measurement accuracy and better aligns with the gold standard, thereby enhancing clinical decision-making.

Alkhader and colleagues conducted a study to determine the effect of volume orientation in CBCT images on the distance between the maxillary sinus floor and the alveolar crest in the posterior maxilla [22]. CBCT scans were taken of 54 implant sites in the posterior maxilla from 34 patients who visited the clinic for implants between January 2018 and January 2019. Vertical distance measurements between the maxillary sinus floor and alveolar crest in the posterior maxilla were evaluated in two scenarios: one with the occlusal plane parallel to the horizon and the other with the mandibular plane parallel to the horizon. Alkhader and colleagues found that the vertical distance was significantly greater when the mandibular plane was parallel to the horizon. These findings emphasize the importance of proper orientation for improving the accuracy of anatomical measurements obtained from CBCT. The present study corroborates these findings and highlights that aligning the occlusal plane parallel to the horizon enhances the alignment of linear measurements with the gold standard, increasing confidence in clinical decision-making.

Min LI and colleagues conducted a study to evaluate the accuracy of linear measurements in CBCT imaging for dental implant applications [23]. Ten edentulous mandibles combined with 10% barium sulfate were utilized in the study to enhance X-ray absorption and delineate the regions of interest. The mandibles were scanned using a Mayer SS-X9010D CBCT machine, and measurements were obtained with DCT Viewer software and compared to reference measurements acquired directly from the mandibles using a calibrated caliper. The study found no significant difference between CBCT measurements and those taken directly with a caliper, while our study provided more comprehensive and precise results. Min LI's study did not examine variables such as the occlusal plane or mandibular plane; instead, it generally assessed CBCT

accuracy and provided an overall evaluation of its capabilities. In contrast, our study demonstrated that aligning the occlusal plane parallel to the horizon enhances the accuracy of height and width measurements of bone.

Maureen van and colleagues conducted a study to evaluate the effect of head position during CBCT imaging on the accuracy of 3D models [24]. A phantom head model was constructed with human skull tissue embedded in silicone to reduce X-ray exposure and scatter. The phantom was imaged using the ProMax 3D MAX CBCT machine with two different KVP settings (90 and 120) and four different FOV settings (standard, elevated, tilted forward, tilted backward). Three-dimensional images were reconstructed from all positions and geometrically compared to the gold standard scan of the skull. Maureen van concluded that head position during CBCT imaging could affect the accuracy of 3D models. While both studies emphasize the importance of patient positioning, our study, focusing on linear measurements and providing more precise guidelines for occlusal plane alignment, is more directly applicable to dental professionals. Concurrently, Maureen van's findings could be valuable in general CBCT system settings and improving the quality of 3D images.

Adibi and colleagues conducted a study to evaluate the effect of head position on CBCT images regarding the proximity of the root apex to the inferior alveolar nerve (IAN) and the accuracy of measurements [25]. CBCT images were obtained from seven human skulls in various standard and tilted positions, and the shortest radiographic distance between the apices of mandibular teeth and the IAN was measured in 20 locations across cross-sectional reconstructions. The study found no statistically significant difference between the measurements in the normal position and other positions. Based on our investigation, however, for cases requiring precise linear measurements (such as bone height and width), accurate positioning of the occlusal plane is essential to obtaining reliable results. A comparison of these two studies suggests that the impact of patient positioning in CBCT imaging may vary depending on the type of data being analyzed and the clinical objectives.

Nikneshan and colleagues conducted a study to examine the accuracy of linear measurements in CBCT imaging at different reconstruction angles [26]. Forty-two titanium pins were placed in seven sheep mandibles, and the pin lengths were measured with a digital caliper. The study found that changing the slice orientation from -12° to $+12^{\circ}$ reduced the accuracy of the linear measurements obtained from CBCT. Although the error was less than 0.5 mm and clinically acceptable, it highlighted a potential limitation in measurement accuracy when deviating from the ideal orientation. Nikneshan's study focuses on the impact of reconstruction angles during image processing, suggesting that even minor changes in the reconstruction angle can lead to reduced accuracy, though this decrease remains clinically acceptable.

These differences raise the question: why do these variations exist? One of the primary factors contributing to measurement discrepancies is operator-related error. In CBCT analysis, manual landmark identification and measurement selection introduce variability, particularly when head orientation changes and anatomic structures appear differently in reconstructed images. When the head position is altered, the spatial relationship of anatomical structures shifts, leading to potential differences in how linear distances are recorded. For example, a structure that appears aligned in one orientation may be measured along a slightly different axis when the orientation changes, influencing height and width measurements.

Although our study was conducted in vitro, our results, along with those of previous research, strongly suggest that accurate CBCT measurements can be achieved when the occlusal plane is oriented parallel to the horizon. This standardized head orientation minimizes measurement errors and should be adopted as a routine practice by CBCT clinicians. Recognizing that technicians may face challenges in accurately identifying the occlusal plane, we recommend additional training in this area. Furthermore, it is essential that the importance of proper head positioning is clearly explained to patients, ensuring their cooperation during image acquisition. We also acknowledge that factors such as soft tissue variability and patient positioning in vivo require further consideration to fully validate these findings.

While the sample size used in our study was determined through a power calculation with a significance level of 0.05 and statistical power of 80%, the small sample size may limit the external validity and generalizability of our findings. The results are statistically valid within the tested sample; however, they may not fully represent the variability of human mandibular anatomy, especially in live patients. Factors such as soft tissue variability, positioning inconsistencies, and patient-specific anatomical differences could affect CBCT measurements in clinical settings that should be considered and investigated in further studies. Therefore, the findings should be interpreted with caution when extrapolating to broader populations.

Conclusion

The findings of this study demonstrate that aligning the occlusal plane parallel to the horizon yields measurements that are closer to those obtained by caliper, as compared to the mandibular plane. Therefore, utilizing

the occlusal plane provides greater accuracy for determining linear bone measurements (height and width). This alignment is essential for dental treatment planning and clinical applications, as it enhances the reliability of CBCT measurements and supports more precise surgical planning. However, given the in vitro nature of this study, further research is necessary to validate these findings in clinical settings. Future in vivo studies should focus on assessing the impact of patient-related factors, such as soft tissue and positioning variability, to further refine CBCT imaging protocols and ensure broader clinical applicability.

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Authors' contributions
RA & AT devised acquisition of data, statistical analysis, administrative, technical, and material support. RG devised study concept and design, drafting of the manuscript, critical revision of the manuscript for important intellectual content, study supervision. MS devised analysis and interpretation of data, administrative, technical, and material support. AT devised statistical analysis, administrative, technical, and material support. RA devised analysis and interpretation of data, administrative, technical, and material support. All authors read and approved the final manuscript.

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Data availability
All data and materials are provided upon request of the journal. Request for data can be directed to the submitting author, Rojin Ardalani (rojin14a@gmail.com) or the corresponding author, Azadeh Torkzadeh (Azadehh.Torkzadeh@gmail.com).

Declarations

Ethics approval and consent to participate
Initially, the research protocol underwent review and approval by the Ethics Committee of Islamic Azad University, Isfahan (Khorasgan) Branch, with the ethics code IR.IAU.KHUISF.REC.1403.079.
As this study was conducted on dry human mandibles, it does not involve human participants, and informed consent to participate is 'not applicable.'

Compliance with the Helsinki declaration
This study complies with the ethical principles of the Declaration of Helsinki. However, as it is an in vitro study conducted on dry human mandibles that were already available in the Department of Anatomy and Basic Sciences, it does not involve human participants or identifiable data.

Consent for publication
Not applicable.

Competing interest
The authors declare no competing interests.

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