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SYSTEMATIC REVIEW

Is there really a relationship between maxillary and mandibular incisor inclination and the amount of surrounding cortical alveolar bone? a systematic review

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Abstract

Background For orthodontists, the position of the incisors is a key factor in setting treatment goals. Achieving maximum stability requires that they be positioned in the medullary portion of the alveolar bone, balanced with the lingual and labial musculature. Incorrect orthodontic movements can result in root resorption, dehiscences, or even fenestrations.

Methods A systematic review of the bibliography was conducted in accordance with PRISMA recommendations. Searches were made in PubMed, Scopus, and Cochrane Library databases, using the same search terms in each, with no limitation on publication data, up to July 1st, 2024. The review accepted articles in any language. Randomized controlled trials, case-control studies, and cohort studies were included, both retrospective and prospective. Systematic reviews, meta-analyses, case reports, case series, literature reviews, and editorials were excluded. The quality of the articles was determined according to the CONSORT criteria.

Results The initial database search identified 167 articles: 89 in PubMed, 74 in Scopus, and 4 in the Cochrane Library. Of these, 75 were duplicates, leaving 92. After applying the inclusion criteria, a total of 8 articles were included in this systematic review.

Conclusions This systematic review highlights the significant relationship between alveolar bone thickness and incisor inclination as assessed by CBCT. The bone thickness varies regionally, with the maxilla generally having thicker palatal bone and the mandible having thinner labial bone. CBCT is indispensable for evaluating cases involving severe skeletal discrepancies, preexisting bone defects, or planned movements beyond the alveolar limits, while traditional methods may suffice for less complex cases. Standardizing methodologies and conducting longitudinal studies with diverse populations are crucial for improving clinical guidelines and ensuring safe, effective treatment planning.

Keywords Upper incisor, Lower incisor, Incisor inclination, Alveolar bone width, Cortical bone, CBCT

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Background

For orthodontists, the position of the incisors is a key factor in setting treatment goals [1]. Achieving maximum stability requires that they be positioned in the medullary portion of the alveolar bone, balanced with the lingual and labial musculature [2]. Incorrect orthodontic movements can result in root resorption, dehiscences, or even fenestrations [3]. It is the orthodontist's responsibility to plan treatment so that the movements made are safe, do not cause iatrogenic effects, and remain within the biological limits of the bone bases. The patient's bone morphology and the biomechanics used during treatment are fundamental factors to consider before starting any orthodontic treatment. An imbalance between the apposition and resorption of the alveolar bone during tooth movement will lead to the tooth moving out of its zone of equilibrium, potentially even exiting the bone [4]. While certain studies have indicated no significant relationship between incisor inclination or protrusion and gingival and bone thickness, others have reported an association. These conflicting findings may stem from disparities and limitations in the methodologies employed to measure tooth inclinations as well as gingival and alveolar bone dimensions [5–9].

Orthodontists must thoroughly evaluate the thickness of the alveolar bone around the maxillary and mandibular incisors to determine the limits of tooth movement. This evaluation aids in ensuring precise torque control and facilitates the delivery of safe treatment, thereby safeguarding patients against iatrogenic bone loss and maintaining periodontal health. Proper torque adjustment is indispensable for attaining optimal occlusion, enhancing facial aesthetics, and ensuring long-term stability. Correcting and controlling the torque of maxillary and mandibular anterior teeth holds significant clinical importance [10].

Traditionally, periapical radiography, panoramic radiography, and lateral cephalograms have been used to detect maxillary alveolar bone levels. However, these two-dimensional imaging methods are prone to distortion, fail to clearly show overlapping structures, and lack the depth needed to measure alveolar bone thickness accurately. Panoramic radiographs, for instance, often suffer from magnification errors, while lateral cephalograms are limited to providing a broad view of craniofacial relationships without offering precise details about bone thickness. Such limitations make it difficult to capture the complexity of the alveolar bone, especially in regions influenced by incisor inclination.

To address these limitations, advanced imaging techniques such as Cone-Beam Computed Tomography (CBCT) have been developed. CBCT offers high-resolution, three-dimensional imaging that eliminates the challenges of distortion and overlapping structures. By enabling precise and reproducible measurements, CBCT allows for a comprehensive evaluation of alveolar bone morphology and its relationship to incisor inclination. Although CBCT involves higher radiation exposure than traditional methods, its application is justified in cases where detailed imaging is essential for accurate diagnosis and treatment planning, as in this review. This makes CBCT an indispensable tool for orthodontic treatment involving complex tooth movements and skeletal relationships.

However, CBCT use raises ethical concerns due to its higher radiation exposure compared to panoramic or periapical radiographs. While the radiation dose is lower than conventional CT [11], it remains significant, particularly in younger patients who are more sensitive to its effects, due to developing tissues and longer cumulative exposure risks. Current clinical guidelines recommend limiting CBCT use to cases where the benefits clearly outweigh the risks. Such cases include those involving significant skeletal discrepancies, pre-existing bone defects, or severe incisor inclinations where traditional imaging is insufficient for accurate diagnosis and treatment planning. By ensuring careful case selection and optimizing imaging protocols to minimize radiation, CBCT can provide detailed quantitative assessments that improve diagnostic accuracy without compromising patient safety [12, 13]. This review highlights CBCT's essential role in advancing our understanding of the relationship between incisor inclination and alveolar bone thickness, which could not be achieved through other imaging modalities.

The aim of this systematic review is to assess the relationship between maxillary and mandibular incisor inclination and the amount of surrounding cortical alveolar bone with cone-beam computed tomography (CBCT).

Methods

Search strategy

A systematic review of the bibliography was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations [14].

Searches were conducted in PubMed, Scopus, and Cochrane Library databases, applying the same search terms across all platforms without restrictions on publication date, up to July 1 st, 2024.

The search strategy combined both MeSH and non-MeSH terms, connected using the Boolean operators AND and OR, to ensure comprehensive retrieval of relevant studies. The primary search terms included: "incisor," "central," "lateral," "alveolar bone," "alveolar cortical bone," "labial bone," "buccal bone," "IMPA," "thickness," "horizontal measure," "dimension," "CBCT," "cone beam," "cone-beam," "computed tomography," "computerized tomography," "tomography," "cone-beam computed tomography," and "inclinat*."

To enhance the scope and ensure no relevant studies were overlooked, synonyms and broader terms were incorporated where applicable. For example, "incisor" was expanded to include terms like "anterior teeth" and "central incisor," while variations of "CBCT" included "cone beam computed tomography," "cone-beam CT," and "computerized tomography." Boolean operators were strategically used to include these terms within the search.

Inclusion criteria

The review accepted articles in any language. Randomized controlled trials, case-control studies and cohort studies were included, both retrospective and prospective studies. Systematic reviews, meta-analyses, case reports, case series, literature reviews and editorials were excluded [15]. The inclusion criteria were articles analyzing patients in permanent dentition that evaluated the relationship between the inclination of maxillary and/or mandibular incisors and the quantity of cortical bone thickness. An additional criterion was a clear explanation of how the inclination was traced, with the quantity of bone measured in millimeters and all measurements made with the teeth in a sagittal projection.

The titles and abstracts of all articles identified in the initial searches were independently assessed by two reviewers. Reviewer agreement on article selection after reading the title and abstract was evaluated using the kappa score [16]. In case of disagreement, a third reviewer was consulted. Once a selection was made based on titles and abstracts, the reviewers read the full texts and recorded the reasons for rejecting any articles that were excluded.

Data extraction and analyzed variables

The following variables were analyzed in each article: type of study (retrospective, prospective or cross-sectional), sample size (gender, age), number of teeth, commercial name of the CBCT unit employed, maxillary or mandibular incisors, bone point measurements along the tooth axis, quantity of bone, type of incisor inclination measurements, obtained results, conclusions and article quality (Table 1).

Quality assessment

The quality of the articles was determined according to the CONSORT criteria adapted by Mattos et al., a method widely employed in numerous systematic reviews. This adaptation evaluates 9 out of the 27 CONSORT criteria, focusing on the quality of the methodology, design,

Table 1 Summary of articles included in the review

Author (year) [reference]	Type of study	*n*(m/f) Mean age (years)	CBCT	Maxilla or mandibula	Slice thickness	Conclusions
Tian et al. (2015) [10]	CS	45 (20/25), 22.1 ± 4.3 (18–30)	NewTom Vgi (QR srl, Verona, Italy)	MX	0,3 mm	Patients with lingual-inclined incisors have lower ABT values at the root apex of the maxillary central incisor than patients with normal and labial-inclined incisors, and they appear to be more vulnerable to bone defects.
Khoury et al. (2016) [18]	CS	47 (16/31), 34	NewTom Vgi (QR srl, Verona, Italy)	MX	Not mentioned	Buccal bone thickness is greater at the apical level when the tooth is more tilted buccally.
Screbrynska-Witek et al. (2018) [21]	CS	100 (39/61), 41,34	Gendex GXCB-500	MND	0,3 mm	A decrease in tooth angulation in relation to the mandibular body correlated with an increase in lingual cortex this.
Khyati et al. (2018) [22]	R	30 (9/21), (16–30)	Planmeca Promax 3D Mid Pro Face	MND	0,6 mm	The mandibular incisor inclination and growth pattern of the patient appear to have no significant impact on the cortical bone thickness and alveolar bone levels.
Lu et al. (2019) [23]	R	60 (34/26), 22 ± 3.93 (18–35)	New-tom VGi evo; NewTom Inc, Italy	MND	0,3 mm	The cortical-bone thickness of the labial-inclination group was highest followed by those of the upright and inclination group.
Linjawi et al. (2020) [19]	CS	135 (70/65), 34.08 ± 13.79	NE	MX	0,4 mm	There's an association between the inclination angle and the anterior maxillary alveolar bone thickness.
Montanha et al. (2022) [20]	CS	30 (11, 19), 39.40 ± 12.06 (18–66)	CS 8100 3D tomography device (Carestream Healt Inc)	MX	0,15 mm	Greater labial inclination is associated with greater apical bone thickness in the central incisors.
Lei et al. (2022) [24]	R	107 (54/53), 24,57	New-tom VGi evo; NewTom Inc, Italy	MX	0,3 mm	There was a strong positive correlation between sagittal angulation and alveolar palatal thickness and a moderate negative correlation between sagittal angulation and alveolar buccal thickness.

CS Cross-sectional study, *R* Retrospective study, *MX* Maxilla, *MND* Mandibula execution, and analysis of each article. Each article is subsequently classified into three levels: low, medium, or high quality [17] (Table 2).

Results

Selection of articles and flow diagram

The initial database search identified 167 articles: 89 in Pubmed, 74 in Scopus, and 4 in the Cochrane Library. Of these, 75 were found to be duplicates, leaving 92. Upon reviewing the titles and abstracts, 16 articles were relevant to the subject under review. Inter-reviewer agreement on article selection was assessed using the kappa score. The kappa value was 0.89 (95% CI: 0.85–0.93), indicating near-perfect agreement according to the interpretation proposed by Landis and Koch [16]. This high level of agreement ensures the reliability and reproducibility of the study selection process, reducing potential bias introduced by subjective judgment. It should be noted, however, that the kappa statistic may be influenced by the prevalence of included articles and the marginal totals in the contingency table, which are inherent limitations of this method. After a critical reading of the full texts, 8 of the 16 articles were excluded for not meeting the inclusion criteria. Full-text articles were excluded for the following reasons: (1) inadequate reporting of alveolar bone thickness measurements; (2) insufficient data for assessing the relationship between tooth inclination and alveolar bone morphology; and (3) studies focusing on posterior teeth rather than anterior teeth. These criteria ensured that only studies meeting the objectives of this review were included. Consequently, a total of 8 articles were included in this systematic review (Fig. 1). The included studies consisted of both cross-sectional studies (CS) and retrospective studies (R).

Qualitative synthesis

Of the 8 articles, 5 were cross-sectional studies and 3 were retrospective studies, of low/moderate quality according to the criteria proposed by Mattos et al. [17].

Five examined the maxillary teeth and the other three examined the mandibular teeth. Of the studies that examined the maxilla, Khoury et al. [18]., and Montanha et al. [20]., studied the incisors and canines, while Linjawi et al. [19]., Tian et al. [10]., and Lei et al. [24]., focused only on the central upper incisors. Of the three studies that focused on the mandible, only Screbrynska-Witek et al., studied the entire anterior segment [21], while the remaining two focused on the lower central incisors [22, 23].

Seven of the studies had been approved by an ethics committee [10, 19–24]. Just one study didn't mention the ethic committee protocol [13]. All the studies explained how they analyzed the CBCT and how they processed all the images.

The method used to measure alveolar bone thickness wasn't the same in all eight studies. Khoury et al., made different cuts along the longitudinal axis of the tooth, coinciding with the cementoenamel junction (CEJ), and at 4, 6, 8, and 10 mm [18]. Linjawi and Montanha et al., made cuts at the level of the alveolar crest, the middle of the root, and the apex [19, 20]. Screbrzynska-Witek et al., made the first cut halfway between the apex and the CEJ, at 6 mm and 3 mm from the apex, and the apex [21]. Tian et al., made ten cuts at the same interval from the CEJ to the apex [10]. Khyiati et al., made cuts at the middle of the root and the apex [22]. Lu et al., made cuts at the level of the CEJ, and at 3, 6, and 9 mm from the apex [23]. Finally, Lei et al., made cuts at the level of the CEJ, the middle of the root, and the apex [24].

These methodological differences may limit the comparability of results, as variations in measurement intervals or reference planes can lead to discrepancies in reported bone thickness. Moreover, inconsistencies in imaging protocols, including differences in voxel size and slice thickness, could further contribute to variability in measurement accuracy. This lack of standardization underscores the need for caution when synthesizing findings from diverse studies and highlights the importance of developing uniform guidelines for future research.

Khoury et al. [18] found that buccal bone thickness was significantly correlated with the inclination of maxillary anterior teeth, specifically at the apical region (10 mm

Table 2 Quality assessment of the articles included in the review

Author (year) [reference]	Inclusion/exclusion	Control group	Blind	Statistics	Reliability of measurements	Drop-outs	Follow-up (years)	Limitations	Total
Tian et al. (2015) [10]	1	0	0	1	1	0	0	0	3
Khoury et al. (2016) [18]	1	0	0	1	1	0	0	0	3
Screbrynska-Witek et al. (2018) [21]	1	0	0	1	0.5	0	0	1	3.5
Khyati et al. (2018) [22]	1	0	0	1	0.5	0	0	1	2.5
Lu et al. (2019) [23]	1	0	0	1	1	0	0	0	3
Linjawi et al. (2020) [19]	1	0	0	1	0.5	0.5	0	0	2
Montanha et al. (2022) [20]	1	0	0	1	0.5	1	0	1	4.5
Lei et al. (2022) [24]	1	0	0	1	0.5	0	0	1	3.5

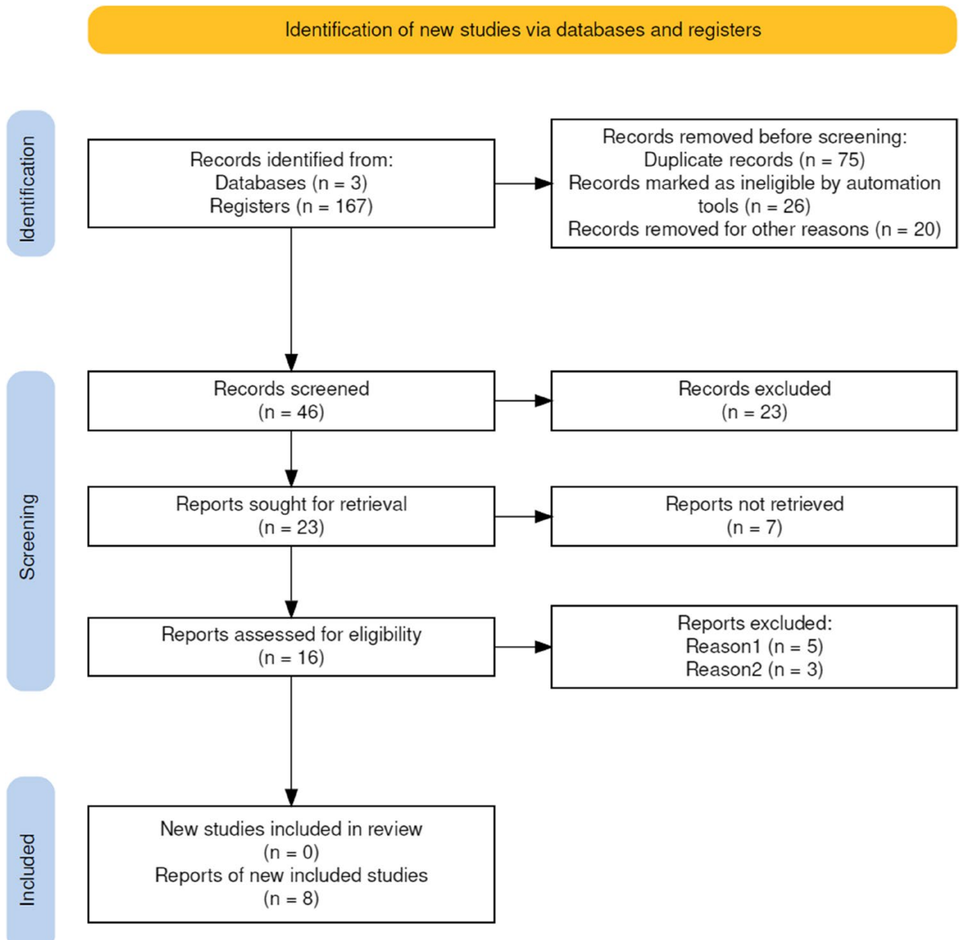

Fig. 1 PRISMA flow diagram

from the CEJ) ($p < 0.05$). At this level, a greater buccal tilt of the tooth (larger obtuse angle) was associated with increased buccal bone thickness ($p < 0.0001$). They also reported that alveolar bone thickness was greater in cases of labial inclination compared to neutral or lingual inclination ($p < 0.05$, 95% CI: 0.8–1.4 mm), indicating a strong relationship between incisor inclination and alveolar bone morphology. These findings align with the results of Linjawi et al., Montanha-Andrade et al., and Lei et al. [19, 20, 24].

Tian et al. [10] identified statistically significant differences in alveolar bone thickness (ABT) exclusively at the root apex. In the lingual-inclined group, labial ABT ($p < 0.01$) and total ABT (labial and palatal combined) ($p < 0.05$) were significantly lower than in the neutral and labial-inclined groups at this level, with a confidence interval of 0.6–1.0 mm. Although labial ABT was lower along the entire root in the lingual-inclined group, these differences were not statistically significant. Measurements of ABT at the CEJ across all groups showed that the bone was very thin at this level. The study concluded that patients with lingual-inclined incisors have lower ABT at the root apex of maxillary central incisors compared to those with normal or labial inclination, making them more prone to apical bone defects. Additionally, fenestrations were more commonly found in the labial alveolar bone of lingual-inclined maxillary incisors.

Montanha-Andrade et al. [20] determined that tooth inclination was positively and significantly associated with apical bone thickness in central incisors, with greater labial inclination linked to increased apical bone thickness ($R = 0.34$, $p = 0.001$). This suggests that labial inclination provides greater apical bone support in central incisors. However, correlations for lateral incisors were not significant, reflecting site-specific variability. These findings emphasize the importance of considering tooth-specific differences in the relationship between inclination and alveolar bone morphology.

Lei et al. [24] established that the sagittal angulation (SA) of maxillary incisors—defined as the angle between the long axes of the tooth and its respective alveolar process—significantly influenced alveolar bone morphology at the apex. A greater labial angulation was correlated with a thicker buccal bone plate and a thinner palatal bone plate ($p < 0.000$), while sagittal angulation was also significantly associated with palatal bone thickness ($p < 0.01$, 95% CI: 1.0–1.6 mm). These findings emphasize that increased sagittal angles correspond to greater bone thickness, with strong reliability reflected across the study cohort.

The three studies that focused on mandibular incisors determined different results. Screbrzynska-Witek et al., studied the lower canines and incisors and found that a decrease in tooth angulation in relation to the mandibular body correlated with an increase in lingual cortex thickness just in mandibular central incisors [21].

Khyati et al. [22] conducted a study to evaluate the effect of mandibular incisor inclination on cortical bone thickness and alveolar bone levels across different skeletal patterns, categorizing patients into three groups based on growth patterns: horizontal, average, and vertical. While no correlation was found between incisor inclination and growth pattern in relation to cortical bone thickness or alveolar bone levels, a positive correlation was observed between mandibular incisor inclination and labial cortical bone thickness ($p = 0.02$). This relationship showed a relatively narrow confidence interval, indicating a precise association, though the small sample size limited the generalizability of the findings.

Lu et al. [23] quantified the effect of labial inclination of mandibular central incisors on cortical and cancellous alveolar bone among patients with low-angle, skeletal Class III malocclusion. Patients were divided into three groups based on the mandibular central incisor-mandibular plane angle: lingual-inclination, upright, and labial-inclination groups. Significant differences in labial cortical bone thickness were observed among the three groups ($p < 0.01$, 95% CI: 0.7–1.5 mm) at multiple levels, including 6 mm and 9 mm below the CEJ, the midpoint between the CEJ and the root apex, and at the root apex, except at 3 mm below the CEJ. The labial-inclination group exhibited the greatest cortical bone thickness, followed by the upright and lingual-inclination groups. These findings underscore the importance of incisor inclination in determining alveolar bone morphology, particularly in patients with low-angle skeletal Class III malocclusion.

Discussion

Our systematic review encompasses only 8 studies that utilized CBCT to measure the quantity of alveolar bone thickness around the incisors and examine the relationship between this thickness and tooth inclination. This limited number of studies is due, in part, to the ethical concerns surrounding radiation exposure, as patients must undergo radiographic examinations. Additionally, the methodological diversity among the few published studies contributes to this limitation.

Efforts are currently being made to reduce the radiation emitted by CBCT machines, especially since many patients undergoing this procedure are children, who are more vulnerable to the harmful effects of radiation. Therefore, it is crucial to maintain an optimal balance between obtaining adequate image quality and minimizing radiation exposure. While CBCT scanners provide precise 3D images of the dentoalveolar complex, it is essential to carefully select cases that will genuinely benefit from this examination and to thoroughly evaluate borderline cases [25]. These include situations where the alveolar bone is clinically too narrow for labio-lingual displacement, patients with periodontal disease, cases requiring tooth movement beyond the alveolar limits, including those that necessitate decisions about tooth extraction, and cases involving transposed or impacted teeth [26, 27]. To minimize radiation exposure, clinical guidelines, such as ALARA (As Low As Reasonably Achievable), recommend limiting CBCT use to cases with clear diagnostic benefits, while using optimized imaging protocols like reduced voxel resolution, smaller fields of view, and shorter exposure times. Modern CBCT machines now include pediatric protocols with lower doses, and advancements in artificial intelligence (AI) promise to further enhance imaging safety by improving diagnostic quality at reduced radiation levels. For less complex cases, two-dimensional imaging remains a viable alternative to avoid unnecessary exposure. By adhering to these strategies and advancements, clinicians can achieve a balance between diagnostic need and patient safety, particularly for children and adolescents. In the future, the use of artificial intelligence will not only help us better diagnose and treat our patients [28], but it will also help us reduce radiation exposure, thereby allowing us to use more CBCT imaging with fewer risks [29]. AI-powered algorithms can significantly enhance image quality by reconstructing diagnostic details from lower-dose CBCT scans, as demonstrated by deep learning image reconstruction (DLIR) techniques. This capability reduces the radiation dose required while maintaining the diagnostic quality necessary for precise evaluations. Beyond diagnosis, AI can optimize imaging protocols by automatically adjusting scan parameters, such as field of view (FOV) and voxel resolution, based on patient-specific requirements. This customization minimizes unnecessary radiation exposure, especially in children and adolescents. Furthermore, AI holds promise for predicting treatment outcomes and optimizing orthodontic biomechanics, potentially reducing the need for repeated imaging [29].

All studies included in this revision, except Linjawi et al. [19]., specified the CBCT equipment used and the technical details of the scanning process.

Fuhrmann et al., showed that quantitative assessment of alveolar cortical bone using computed tomography (CT) is feasible above a minimum bone thickness of 0.5 mm, and obtained results that were statistically similar to histological measurements [30]. The accuracy to evaluate the alveolar bone is directly proportional to the voxel size. Modern equipment's are able to use voxel sizes of $0.3 \times 0.3 \times 0.3$ mm, which is a threshold smaller than the one stated by Fuhrmann, and therefore giving accurate measurements [23].

Handelman suggests that bone loss can be affected by treatment involving extractions and the force applied during orthodontic procedures. Dehiscence and fenestrations are potential outcomes when incisors are either protruded or retruded; protrusion of the maxillary incisors may result in dehiscence of the alveolar cortical bone on the labial side, whereas retrusion may affect it on the palatal side [31]. Elnagar et al. also proposed that while the labial cortical plates adapt to follow incisor movement, the maxillary and mandibular lingual cortical plates do not. This suggests that lingual cortical plates may serve as a limitation to planned orthodontic tooth movement [32].

Vardimon et al., contend that the cortical plate of alveolar bone is subject to remodeling during treatment, resulting in alterations to its shape and position, but with a ratio of bone remodeling to tooth movement (B/T) different then 1:1 [33]. This stance supports Handelman's hypothesis, which posited limitations on tooth movement due to the cortical plates [31].

In addition to observing the relationship between tooth inclination and bone quantity, some studies have also examined the relationship of bone quantity with other potential factors. Khoury et al. [18]., found no relationship between tobacco use and bone quantity, nor with gender or age. However, this contradicts findings by Linjawi et al. [19]., and Montanha et al. [20]., who did find a significant relationship with gender, where men demonstrated greater alveolar bone quantity. This gender-based variation suggests that conclusions drawn from mixed-gender populations may not be fully generalizable to gender-specific groups. Similarly, Khoury et al. [18] observed no significant association between age and bone thickness, whereas other studies have indicated that bone remodeling and density decline with age, which could impact the accuracy of bone thickness measurements and orthodontic treatment outcomes in older adults.

These findings emphasize the importance of considering demographic diversity when interpreting the results of this review. Variability in gender and age distribution across the included studies may contribute to differences in reported outcomes, underscoring the need for future research to stratify analyses by demographic factors to improve the generalizability of findings. Incorporating these considerations into treatment planning is also essential, as the effects of tooth movement on alveolar bone morphology may differ based on the patient's gender and age.

Two studies examined the relationship between Class III malocclusion and bone quantity. Lu et al. [23]., focusing on mandibular incisors, concluded that alveolar bone morphology is significantly related to the labial inclination of these teeth, and this inclination is closely associated with patients with Class III malocclusion. Lei et al. [24]., support this same result in the maxillary central incisors, determining that the Class III canine relationship is associated with more palatalized incisors and therefore less bone thickness. As for the patient's growth type, Khyati et al. [22]., found no significant differences between it and bone quantity.

They have also related gingival biotype to bone quantity. Khoury et al. [18]., found that bone thickness was notably greater when the gingival biotype was thick. Furthermore, fenestrations were more commonly found on the labial alveolar bone of lingual-inclined incisors, as indicated by Tian et al. [10].

Finally, Screbrynska-Witek et al. [21]., didn't observed relationship between cortical bone thickness and the angulation of the cortical plate and tooth rotation.

The regional differences in alveolar bone morphology between the maxilla and mandible have critical clinical implications for orthodontic treatment planning and risk mitigation. In the maxilla, the thinner labial cortical bone in cases of lingual-inclined incisors, as demonstrated by Tian et al. [10], highlights the increased risk of labial fenestrations or dehiscence when planning significant tooth movements. This demonstrates the importance of carefully evaluating bone morphology at the root apex during orthodontic diagnosis, especially for cases involving proclination or retraction of maxillary incisors. In contrast, studies focusing on the mandible, such as those by Khyati et al. [22] and Lu et al. [23], emphasize the association between labial inclination and increased cortical bone thickness. While this relationship suggests more apical bone support for labial-inclined mandibular incisors, the limited adaptability of lingual cortical plates, as noted by Elnagar et al. [32], suggests that excessive lingual tipping may still pose a risk of cortical bone loss or dehiscence.

Orthodontists should incorporate these findings into treatment planning by prioritizing three-dimensional imaging in cases with suspected alveolar bone limitations, such as severe inclinations or skeletal discrepancies. CBCT imaging enables practitioners to visualize thin regions of bone and avoid orthodontic movements that exceed the boundaries of the alveolar bone, ultimately reducing the risk of complications such as bone loss or root resorption. Additionally, tailored force application and biomechanics should consider the variable remodeling capacity of cortical plates between the maxilla and mandible, as suggested by Vardimon et al. [33], to optimize treatment outcomes while minimizing adverse effects.

The findings from this review demonstrate the significant influence of incisor inclination on alveolar bone morphology, with variations observed based on anatomical region, tooth type, and skeletal patterns. While most studies highlighted significant correlations, discrepancies in measurement methods and imaging protocols contribute to variability in reported outcomes. The statistical analyses across the included studies demonstrated consistent trends in the relationship between incisor inclination and alveolar bone thickness. Most studies reported statistically significant findings ($p < 0.05$) with confidence intervals indicating moderate precision. However, variability in sample sizes, imaging protocols, and methodologies may influence the generalizability of these results. Future studies should aim to standardize statistical reporting and methodologies to enhance comparability and reliability across studies.

Limitations

One limitation of this systematic review could be the different cephalometric values that have been chosen to calculate the inclination of each tooth. Khoury et al. [18]., used the angle of the tooth axis with the horizontal plane. Lei et al. [24]., chose the angle created between the tooth axis and the alveolar axis. Other studies examining maxillary teeth used the axis between the upper incisor and the palatal plane [10, 19, 20]. On the other hand, the long axis of the mandibular central incisor and the mandibular plane was used in all the studies [21–23].

Additionally, the axial slice thickness of the CBCT scans varied among the included studies, ranging from 0.6 mm to 0.15 mm. This variation in slice thickness may influence the accuracy and resolution of bone measurements, potentially affecting the comparability of results. While all studies employed CBCT imaging, differences in imaging protocols and resolutions could introduce variability in the reported outcomes.

Conclusions

This systematic review highlights the significant relationship between alveolar bone thickness and incisor inclination as assessed by CBCT. Studies consistently show that naturally labially inclined incisors have thicker labial bone, while lingually inclined incisors have thinner labial bone, increasing the risk of periodontal complications. The bone thickness varies regionally, with the maxilla generally having thicker palatal bone and the mandible having thinner labial bone.

Orthodontic treatment planning must account for these variations to avoid adverse outcomes. CBCT provides precise measurements that are crucial in specific clinical scenarios, such as cases involving severe skeletal discrepancies, transposed or impacted teeth, preexisting bone defects, or planned movements beyond the alveolar limits. In less complex cases, traditional methods like panoramic and cephalometric radiographs may suffice.

Factors such as age and sex influence bone thickness, with males typically having thicker bone. Future research should address the limitations noted in this review, particularly by standardizing CBCT methodologies (e.g., slice thickness, voxel size) and developing consistent patient selection criteria. Longitudinal studies with larger, diverse populations are essential to validate the relationship between incisor inclination and alveolar bone thickness and to establish clinically actionable guidelines.

In conclusion, understanding the relationship between incisor inclination and alveolar bone thickness is essential for safe and effective orthodontic treatment. CBCT plays a key role in assessing these relationships, particularly in complex cases where precise imaging is critical to treatment planning and risk mitigation.

Abbreviations

ABT	Alveolar bone thickness
CBCT	Cone-beam computed tomography
CEJ	Cementoenamel junction
CS	Cross-sectional study
MND	Mandibula
MX	Maxilla
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
R	Retrospective study
SA	Angle between the long axes of the tooth and its respective alveolar process

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Authors' contributions
N.G.d'O., A.M-G., and P.V-C., performed equally with the study selection, data extraction, and data presentation. They also completed the initial manuscript draft and data analysis. N.G.d'O., conceptualized the study and resolved disagreements in study selection; he analyzed all data and prepared the presentation of the final manuscript. A.A., and A.C., supervised the research activity and provided the necessary resources to conduct the review. All authors contributed to critical revision of the article. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study available from the corresponding author upon reasonable request.

Declarations

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Competing interests
The authors declare no competing interests.

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