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REVIEW ARTICLE

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Alveolar bone changes in maxillary and mandibular anterior teeth during orthodontic treatment: A systematic review and meta-analysis

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Abstract

The association between tooth movement and remodelling of surrounding bone is controversial. To analyse the effect of tooth movement on alveolar bone changes in maxillary and mandibular anterior teeth by cone-beam computed tomography (CBCT). The Embase, Cochrane Library and Medline databases were searched without any language restrictions. Longitudinal studies using CBCT to observe alveolar bone changes of maxillary and mandibular anterior teeth during orthodontic treatment were included. Two independent reviewers performed the study selection, data extraction and methodological quality assessment. A total of 26 studies were included in this review, 14 of which were eligible for quantitative synthesis. In extraction cases, meta-analysis showed vertical bone loss on the labial (0.36 mm) and lingual (0.94 mm) sides of maxillary incisors, and lingual bone thickness decreased significantly at the cervical level (0.57 mm). In non-extraction cases, vertical alveolar bone loss was significant on the labial side (0.97 mm) and lingual side (0.86 mm) of mandibular incisors. Subgroup analysis for skeletal class III patients indicated that vertical alveolar bone loss was 1.16 mm on the labial side and 0.83 mm on the lingual side of mandibular incisors. The absence of high-quality studies and the high heterogeneity of the included studies were limitations of this systematic review and meta-analysis. Based on limited evidence, alveolar bone height and thickness, especially at the cervical level, decreased during both labial and lingual movement of anterior teeth.

KEYWORDS

alveolar bone, anterior teeth, orthodontics, systematic review

1 | INTRODUCTION

Bone remodelling secondary to tooth movement is fundamental for orthodontic treatment. Bone remodelling is dominantly influenced by the morphology of alveolar bone and orthodontic procedures.[1] It is widely accepted that orthodontic movement should allow the tooth to remain within the bone.[2-4] Once tooth movement exceeds the alveolar bone boundary, dehiscence and fenestration occur. Proffit proposed the 'envelope of discrepancy' to represent the limits of tooth movement.[5] Excessive retraction of anterior teeth in patients with bimaxillary protrusion increases the risk of periodontal deterioration.[6-8] The morphology of alveolar

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bone in high-angle patients, especially skeletal class III patients, is reported to be thinner than the morphology of alveolar bone in low-angle and average-angle patients.[9] Hence, the movement of lower incisors in skeletal class III patients with thin alveolar bone could also result in alveolar bone loss.[10,11] Considering the amount of tooth movement and alveolar bone anatomy, anterior teeth are vulnerable to alveolar bone loss.

Due to the limitations of conventional two-dimensional radiographs, lateral cephalograms and panoramic radiographs cannot accurately assess alveolar bone loss. Cone-beam computed tomography (CBCT) visualizes the morphology of the tooth root and alveolar bone in three dimensions; thus, CBCT has become more mainstream in diagnostics and orthodontic treatment planning.[12] At present, CBCT is used to assess alveolar bone height and thickness with high accuracy and precision.[13] Previous studies have assessed alveolar bone changes in the anterior region during orthodontic treatment using CBCT. However, the results are inconsistent. In extraction cases, the amount of alveolar bone gain on the labial side and the amount of alveolar bone loss on the lingual side remain unclear. Sarikaya et al observed that labial alveolar bone changes in maxillary incisors were minimal,[14] which could be attributed to measurement error, whereas Liu et al reported an increase in labial alveolar bone thickness during treatment.[15] In non-extraction cases, labial movement of anterior teeth could jeopardize periodontal health as well, and the frequency of bone deficiency in the anterior region was not well reported in previous studies. In addition, orthodontic treatment in patients with periodontitis warrants special periodontal consideration. Currently, there is a lack of evidence on the effect of tooth movement on alveolar bone levels in patients with periodontitis.

At present, bone remodelling during orthodontic treatment is still controversial. To avoid iatrogenic bone loss during orthodontic treatment, it is important to understand the bone remodelling ability of the patient and establish the amount of tooth movement prior to orthodontic treatment. This systematic review and meta-analysis analysed the effect of tooth movement on alveolar bone changes, as measured by CBCT, of both maxillary and mandibular anterior teeth. The primary objective was to evaluate alveolar bone changes during labial movement of anterior teeth for non-extraction treatment and the lingual movement of anterior teeth for extraction treatment. The secondary objective was to analyse alveolar bone changes in skeletal class III patients and periodontitis patients during orthodontic treatment.

2 | METHODS

2.1 | Protocol and registration

This systematic review and meta-analysis was conducted in accordance with the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and was registered in the International Platform of Registered Systematic Review and Meta-Analysis Protocols.

2.2 | Eligibility criteria

Eligibility criteria were in accordance with the Participant Intervention Comparison Outcome Study (PICOS).

2.2.1 | Type of study

Longitudinal studies, both retrospective and prospective, using CBCT to determine alveolar bone changes in maxillary and mandibular anterior teeth during orthodontic treatment were included. These included randomized controlled trials (RCTs), controlled clinical trials, cohort studies and self-controlled studies. Reviews, cross-sectional studies, case reports and animal studies were excluded.

2.2.2 | Type of participants

Orthodontic patients with permanent dentition who were treated with a fixed appliance were included. This review focused on the effect of tooth movement in alveolar bone. Hence, patients were not excluded on the basis of occlusion, age, sex or treatment plan (extraction or non-extraction, orthodontic or orthodontic-orthognathic treatment). Extraction treatments consisted of extracting first premolar teeth and retracting anterior teeth. Patients undergoing any other extraction treatment were excluded. Orthodontic patients with well-controlled periodontitis were also included and analysed separately.

2.2.3 | Type of intervention

Included patients were treated with full-mouth brackets. Patients were not excluded on the basis of the type of bracket (traditional metal bracket, ceramic bracket, lingual bracket or self-ligated bracket), technique (straight-wire technique, tweed technique or edgewise technique) or treatment duration.

2.2.4 | Type of comparison

Considering the absence of untreated control group in current clinical research, only self-controlled studies assessing the alveolar bone level during orthodontic treatment were included in this systematic review. The post-treatment alveolar bone level was compared to the pre-treatment alveolar bone level.

2.2.5 | Type of outcome measures

Changes in alveolar bone measurements in the anterior region of the maxilla and mandible, as analysed by CBCT, were the outcome

TABLE 1 Search strategy for Medline via PubMed

Literature search was conducted up to 2020/04		PubMed results
# 1	orthodontics [Mesh] OR orthodontic* OR tooth movement OR teeth movement	84030
# 2	cone-beam computed tomography [Mesh] OR Spiral cone-beam [Mesh] OR computed tomography OR volume computed tomography OR computed tomography OR computerized tomography, cone-beam OR cbct OR CAT scans, cone-beam	547480
# 3	alveolar bone OR dentoalveolar bone OR alveolar ridge OR bone volume OR bone height OR bone thickness OR bone loss OR bone width OR alveolar bone loss [Mesh]	251967
#4	OR alveolar process [Mesh] anterior teeth OR anterior tooth OR incisor [Mesh] OR canine OR cuspid [Mesh]	391152
#5	#1 AND #2 AND #3 AND #4	486

measures. The primary outcome measures were alveolar bone height and thickness. Other bone measurements that reflect alveolar bone changes during orthodontic treatment, such as bone density and bone volume, were also of interest.

2.3 | Literature search strategy

We searched the Embase, Cochrane Library and Medline (via PubMed) databases from their inception up to April 2020, without any language restrictions. The search strategy employed for PubMed is detailed in Table 1. Similar searches using revised key words were conducted for the Cochrane Library and Embase databases with the assistance of a librarian. Furthermore, the reference lists of the selected articles were manually searched for additional studies.

2.4 | Study selection

Two independent authors screened, selected and assessed all identified studies. After eliminating duplicate studies, the titles and abstracts of all studies were examined. Full texts were carefully read when titles and abstracts did not provide sufficient data. Any disagreement on article selection was resolved by consultation and discussion with a third author.

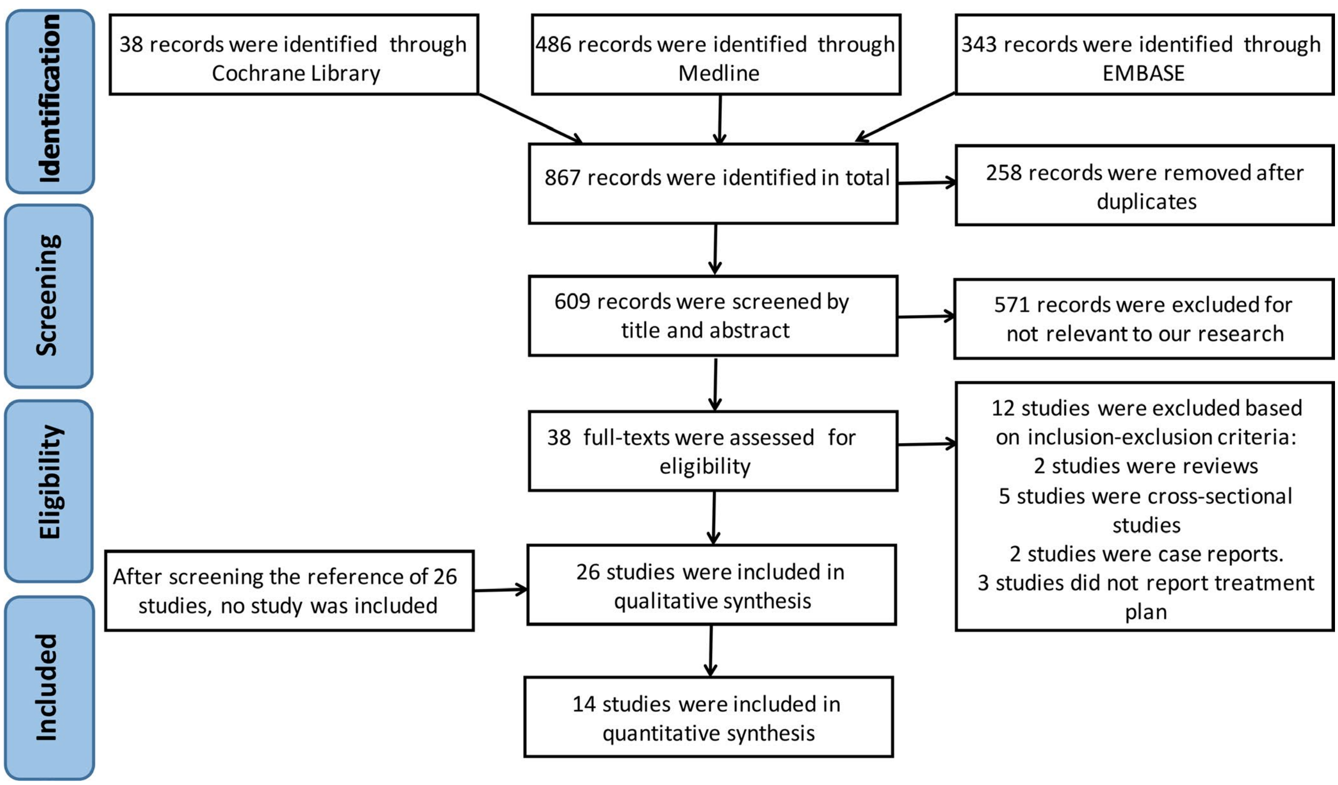

FIGURE 1 Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flow diagram [Colour figure can be viewed at wileyonlinelibrary.com]

2.5 | Data extraction

Study characteristics including design, sample size, tooth site, patient age, diagnosis and treatment plan, duration of observation, measurements used to evaluate alveolar bone and outcomes were independently extracted by two authors. The outcomes included bone thickness at three levels (cervical, middle and apical), bone height and bone density around anterior teeth. The time between CBCT scans was recorded to determine the duration of observations.

2.6 | Methodological quality assessment

Assessments of the quality of the included studies were independently performed by two authors. For RCTs, the risk of bias tool of the Cochrane Collaboration was used to evaluate the risk of bias. The Methodological Index for Nonrandomized Studies (MINORS) was used to evaluate the methodological quality of non-randomized clinical studies. For non-controlled studies, such as self-controlled studies, only the first 8 of the 12 MINORS criteria were assessed. The overall quality of evidence for outcomes was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. Cases of disagreement were resolved by consultation and discussion with a third author.

2.7 | Data synthesis

A meta-analysis was conducted on the quantitative data using Review Manager 5.3 (Nordic Cochrane Centre, Cochrane Collaboration, Copenhagen, Denmark). In consideration of the high clinical heterogeneity among the included studies, a random effect model was used for analysis.[16] In addition, subgroup analyses were performed based on tooth movement direction and periodontal status (extraction cases, non-extraction cases, severe skeletal III cases and periodontitis cases). Among the extraction cases, subgroup analyses were further carried out based on the treatment duration (before and after anterior teeth retraction, before and after orthodontic treatment). Statistical heterogeneity was assessed using the chi-square and I-square tests. I^2 values of 25%, 50% and 75% indicated low, moderate and high heterogeneity, respectively. *P*-values ≤ .05 were considered statistically significant. Studies with methods and outcomes that could not be quantitatively analysed were described qualitatively.

3 | RESULTS

3.1 | Study selection

After eliminating duplicate studies, a total of 609 studies were identified during the electronic search. After examining titles and abstracts, 38 studies satisfied the criteria for further full-text evaluation. Of those 38 studies, 12 were excluded based on the exclusion criteria. Thus, 26 studies met the eligibility criteria and were included in the review. Among these studies, 14 were eligible for quantitative synthesis. A flowchart of the study identification process is presented in Figure 1.

3.2 | Study characteristics

The 26 studies included 2 randomized clinical trials, 3 cohort studies and 21 self-controlled studies. Measurements of bone height and bone thickness at the cervical (S1), middle (S2) and apical (S3) levels on the labial and lingual sides of anterior teeth were synthesized and are illustrated in Figure 2. Based on the tooth movement direction and periodontal status, the included studies were divided into four subgroups for assessment: 14 studies[6,7,14,15,17-25] with extraction (lingual movement of anterior teeth), 7 studies[25-31] without extraction (labial movement of anterior teeth), 3 studies[10,11,32] including skeletal class III patients (labial movement of mandibular anterior teeth with thin alveolar bone) and 3 studies[33-35] including well-controlled periodontitis patients (with periodontally compromised anterior teeth). Study characteristics are summarized in Table 2, and the outcomes of the included studies are listed in Table S1.

3.3 | Assessment of methodological quality

The risk of bias in the RCT of Puttaravuttiporn et al was low,[35] whereas the risk of bias was high in Preeti et al due to the absence of blinding (Table 3).[20] The MINORS score of three cohort studies was 15 out of 24 (range from 14 to 16).[11,25,34] Regarding the self-controlled studies, MINORS scores ranged from 8 to 14 out of a possible

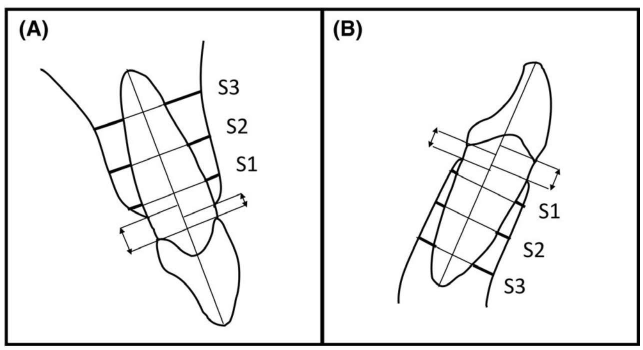

FIGURE 2 Schematic of bone height and bone thickness in maxillary incisors (A) and mandibular incisors (B). The long axis of the tooth was selected as the reference line. Bone height was measured as the distance between the cementoenamel junction and alveolar crest, parallel to the long axis of the tooth. Bone thickness was measured as the distance between the root surface and the cortical plate, perpendicular to the long axis of the tooth, at 3 (S1), 6 (S2) and 9 (S3) mm from the cementoenamel junction

16 (Table 4). The majority of self-controlled studies were retrospective, indicating a potentially high risk of bias. The lack of consistent measurement and small sample size represented additional methodological limitations of the included studies.

3.4 | Changes in the alveolar bone of anterior teeth during extraction treatment

In 14 studies, alveolar bone was measured during extraction treatment, and anterior teeth were retracted with the first premolar extracted. Maxillary and mandibular anterior teeth were analysed, both quantitatively and qualitatively.

3.4.1 | Maxillary anterior teeth

Regarding maxillary central incisors, 14 studies evaluated alveolar bone changes. Three studies[21,24,36] quantitatively evaluated bone height changes, and seven[14,15,17,22,24,25,36] quantitatively evaluated bone thickness at the S1, S2 and S3 levels. To eliminate the potential heterogeneity accompanying different follow-up durations, subgroup analysis was performed. After orthodontic treatment, the bone height on the labial side was significantly increased (mean difference, 0.36; 95% confidence interval (CI), 0.03, 0.70; $P = .04$) according to the meta-analysis results (Figure 3). Bone height on the lingual side also showed a non-significant increase (mean difference, 0.94; 95% CI, −0.03, 1.90; $P = .06$). Regarding bone thickness, labial bone thickness showed an increasing tendency at the S1, S2 and S3 levels 1-3 months after retraction. However, labial bone thickness returned to its original level after orthodontic treatment according to subgroup analysis (Figure 4). Lingual bone thickness at the S1 level showed a significant decrease both (a) 1-3 months after retraction (mean difference, −0.61; 95% CI, −1.11, −0.12; $P = .02$) and (b) after orthodontic treatment (mean difference, −0.57; 95% CI, −0.96, −0.18; $P = .004$). Compared with the changes in lingual bone thickness 1-3 months after retraction, the decrease in lingual bone thickness at the S2 and S3 levels was less obvious after orthodontic treatment (Figure 5). Regarding the maxillary lateral incisors and canines, bone thickness changes were similar to those of maxillary central incisors.[7]

3.4.2 | Mandibular anterior teeth

Regarding mandibular central incisors, four studies evaluated alveolar bone changes.[7,14,15,23] Quantitative synthesis could not be performed due to the high clinical heterogeneity and inconsistent methodology among studies. The results of all these studies showed a significant decrease in lingual bone thickness at the S1 level, and three studies observed that lingual bone thickness decreased at the S2 and S3 levels. The changes in labial bone thickness remain controversial. Two studies[15,36] reported an increase in labial bone thickness, while another two studies[7,14] reported a decrease in labial bone thickness at the S1 level. According to Sarikaya et al, the four mandibular incisors showed similar amounts of alveolar bone loss.[14] However, no study reported alveolar bone changes in mandibular canines in extraction cases.

3.5 | Changes in the alveolar bone of anterior teeth during non-extraction treatment

A total of 6 non-extraction studies reported changes in the alveolar bone during labial movement of anterior teeth. Among these studies, three analysed dental class I patients,[28,30,31] two analysed dental class I and class II patients,[26,29] and one analysed skeletal class II patients.[27]

3.5.1 | Maxillary anterior teeth

Four studies evaluated alveolar bone changes in maxillary anterior teeth.[25,26,28,31] A reduction of labial alveolar bone during labial movement of maxillary anterior teeth is commonly reported. Among these, maxillary canines had the highest rate of alveolar bone dehiscence after orthodontic treatment.

3.5.2 | Mandibular anterior teeth

A total of five studies evaluated alveolar bone changes in mandibular anterior teeth. Given the limited number of studies, only alveolar bone height was analysed quantitatively. Among these studies, three evaluated the labial side,[27,29,31] and two evaluated the lingual side.[29,31] As shown in Figure 6A, meta-analysis revealed a significant difference in the change in alveolar bone height on both the labial side (mean difference, 0.97; 95% CI, 0.42, 1.53; $P = .0006$) and lingual side (mean difference, 0.86; 95% CI, 0.24, 1.47; $P = .0006$).

3.6 | Changes in alveolar bone of mandibular anterior teeth in skeletal class III patients

A total of three studies analysed the decompensation ability of mandibular anterior teeth in skeletal class III patients.[10,11,32] Regarding alveolar bone height, meta-analysis showed a non-significant increase on the labial side (mean difference, 1.16; 95% CI, −0.08, 2.41; $P = .07$) and a significant increase on the lingual side (mean difference, 0.83; 95% CI, 0.05, 1.60; $P = .04$). Regarding bone thickness, all these studies reported that alveolar bone thickness on the labial side was significantly reduced after presurgical orthodontic treatment, except for the labial bone thickness at the S3 level.

TABLE 2 Characteristics of the included studies

Author/Year	Study design	Sample size	Average age	Tooth site
Ahn et al 2013	Self-controlled study	37	26.6 ± 8.5 y	Maxillary central incisor, lateral incisor and canine
Ahn et al 2016	Cohort study	Augmented corticotomy group: 15 Control group: 15	Group A: 23.1 ± 6.2 y Group B: 21.5 ± 3.3 y	Mandibular central incisor, lateral incisor and canine
Castro et al 2016	Self-controlled study	30	13.3 y	Maxillary and mandibular anterior and posterior teeth
Chang et al 2012	Self-controlled study	8	20-25 y	Maxillary central incisor, lateral incisor and canine
Chen et al 2018	Self-controlled study	22	11.5 ± 16.4 y	Maxillary central incisor and lateral incisor
Garlock et al 2016	Self-controlled study	57	18.7 ± 10.8 y	Mandibular central incisor
Guo et al 2011	Self-controlled study	20	22.3 ± 3.2 y	Maxillary central incisor
Lee et al 2012	Self-controlled study	25	26.3 ± 2.7 y	Mandibular central incisor and lateral incisor
Liu et al 2016	Self-controlled study	30	12-18 y	Maxillary and mandibular anterior teeth
Ma et al 2015	Cohort study	Periodontitis group: 40 Control group: 41	Group A: 34.4 y Group B: 29.3 y	Maxillary and mandibular anterior teeth
Maspero et al 2019	Self-controlled study	22	13 y (11-16 y)	Maxillary and mandibular anterior and posterior teeth
Matsumoto et al 2020	Self-controlled study	60	11.2 ± 1.59 y	Mandibular central incisor
Morais et al 2018	Self-controlled study	22	11-17 y	Maxillary central incisor
Nayak et al 2013	Self-controlled study	10	15 ± 3 y	Maxillary and mandibular anterior teeth
Oliveira et al 2016	Self-controlled study	11	18-26 y	Maxillary anterior teeth
Picanço et al 2013	Cohort study	Extraction group: 6 Non-extraction group: 6	Group A: 15.8 ± 4.87 y Group B: 18.3 ± 6.43 y	Maxillary central incisor
Preeti et al 2014	Randomized Clinical Trial	Corticotomy group: 10 Control group: 10	Group A: 19.8 ± 3.22 y Group B: 18.8 ± 3.48 y	Maxillary central incisor and lateral incisor
Puttaravuttiporn et al 2018	Randomized Clinical Trial	Biting exercise group: 18 Control group: 18	42.3 ± 6.5 y	Maxillary central incisor
Sarikaya et al 2002	Self-controlled study	19	14.1 ± 2.3 y	Maxillary and mandibular central and lateral incisor
Sun et al 2015	Self-controlled study	15	Not mention (older than 18 y)	Mandibular central incisor and lateral incisor
Wang et al 2018	Self-controlled study	37	14.5 y (12-18 y)	Maxillary central incisor
Yodthong et al 2013	Self-controlled study	23	20.4 ± 2.7 y	Maxillary and mandibular central incisor
Zasčiurinskienė et al 2019	Self-controlled study	25	45.4 y (26.3-69.7 y)	All the teeth

Diagnosis	Treatment Plan	Duration of observation	Alveolar bone measurement
Dental Class I	Extraction of four first premolars (maximal anchorage)	T1: pre-treatment T2: 1 mo after retraction	Measurement of alveolar bone thickness and height
Dental and Skeletal Class III	orthodontic-orthognathic treatment	T1: pre-treatment T2: before surgery	Measurement of alveolar bone thickness and height on the labial side
Dental Class I	Non-extraction	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone height
Not mentioned	Non-extraction	T1: pre-treatment T2: 7 mo after treatment	Measurement of alveolar bone density
Dental Class I And Class II division I	Extraction of first maxillary premolars (implant anchorage)	T1: pre-treatment T2: 3 mo after retraction	Measurement of alveolar bone thickness and height
Dental Class I and Class II	Non-extraction	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone thickness and height
Bimaxillary dentoalveolar protrusion	Extraction of four first premolars (implant anchorage)	T1: after implant miniscrews T2: post-treatment	Measurement of alveolar bone height
Dental and Skeletal Class III	orthodontic-orthognathic treatment	T1: pre-treatment T2: before surgery T3: post-treatment	Measurement of alveolar bone thickness and height
Dental Class I Skeletal Class I	Extraction of four first premolars (maximal anchorage)	T1: pre-treatment T2: 1 mo after retraction	Measurement of alveolar bone thickness
Dental Class II	Orthodontic-periodontal treatment	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone height and bone density
Dental Class I	Non-extraction	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone thickness and height
Dental and Skeletal Class II	Non-extraction	T1: pre-treatment T2: post-treatment	Measurement of labial alveolar bone thickness and height
Dental Class I and Class II	Non-extraction	T1: pre-treatment T2: after alignment	Measurement of labial alveolar bone thickness and height
Bimaxillary dentoalveolar protrusion	Extraction of four first premolars	T1: pre-treatment T2: 3 mo after retraction	Measurement of alveolar bone thickness
Dental Class I And Class II division I	Extraction of first maxillary premolars	T1: pre-treatment T2: 1 mo after retraction	Measurement of alveolar bone thickness
Group A: Dental Class II Group B: Dental Class I and Class III	Group A: Extraction of first maxillary premolars Group B: Non-extraction	T1: pre-treatment T2: 18 mo after treatment had started	Measurement of alveolar bone thickness
Not mentioned	Extraction of first maxillary premolars with and without corticotomy	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone thickness
Periodontitis	Orthodontic-periodontal treatment	T1: pre-treatment T2: post-treatment T3: 1 mo after treatment T4: 7 mo after treatment	Measurement of alveolar bone thickness, height and density
Dentoalveolar bimaxillary protrusion	Extraction of four first premolars (enhanced anchorage)	T1: pre-treatment T2: 3 mo after retraction	Measurement of alveolar bone thickness
Dental and Skeletal Class III	orthodontic-orthognathic treatment	T1: pre-treatment T2: 1 mo before surgery	Measurement of alveolar bone thickness and height
Maxillary protrusion	Extraction of first maxillary premolars (implant anchorage)	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone thickness and height
Not mentioned	Extraction	T1: pre-retraction T2: post-retraction	Measurement of alveolar bone thickness
Periodontitis	Orthodontic-periodontal treatment	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone height

(Continues)

TABLE 1 (Continued)

Author/Year	Study design	Sample size	Average age	Tooth site
Zhang et al 2015	Self-controlled study	62	21.6 ± 5.2 y	Maxillary and mandibular anterior teeth
Zhang et al 2019	Self-controlled study	36	20.6 ± 2.4 y	Maxillary and mandibular central incisor
Zhou et al 2018	Self-controlled study	40	13.9 ± 2.1 y	Maxillary central incisor and lateral incisor

TABLE 3 Assessment of risk of bias for the RCT using Cochrane's risk of bias tool

Study	Year	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias	Overall bias
Preeti et al	2014	Unclear	No	No	No	No	No	No	High risk
Puttaravuttiporn et al	2008	Yes	Yes	Yes	Yes	No	No	No	Low risk

3.7 | Changes in alveolar bone of anterior teeth in patients with periodontitis

Three studies analysed alveolar bone changes in patients with periodontitis, and all agreed that orthodontic treatment with regular periodontal maintenance did not result in alveolar bone loss and even increased the alveolar bone level in some cases.[33-35]

3.8 | Risk of bias across studies and additional analysis

Due to the limited number of included studies in each meta-analysis, it was not possible to assess publication bias. The overall quality of evidence for the outcome assessment by GRADE is shown in Table 5. The quality of evidence was quite low in this systematic review.

4 | DISCUSSION

Alveolar bone deficiencies, such as fenestration and dehiscence, are common during orthodontic treatment.[37-39] However, the relationship between tooth movement and alveolar bone change remains unclear. This review and meta-analysis aimed to evaluate the effect of tooth movement on the alveolar bone of maxillary and mandibular anterior teeth.

In the extraction group, the results showed that vertical alveolar bone loss occurred on both the labial and lingual sides of maxillary incisors, and the lingual alveolar bone thickness at the S1 level was also significantly decreased after orthodontic treatment. The retraction force is concentrated at the cervical level, leading to significant cervical alveolar bone loss. The labial and lingual alveolar bone thickness at the S3 level was stable. Regarding mandibular incisors, a decrease in alveolar bone thickness on the lingual side was consistently reported, while only two studies supported an increase in alveolar bone thickness on the labial side. The changes in bone thickness in both maxillary and mandibular incisors were in accordance with the pressure-tension theory of bone apposition on the tension side and bone resorption on the pressure side.[39] Our findings suggest that bone remodelling mainly involves bone resorption on the lingual side, while bone deposition on the labial side is limited. In addition, the reduced alveolar bone height could result in iatrogenic dehiscence and gingival recession. In extraction cases, mandibular anterior teeth are more vulnerable to bone defects during retraction compared with maxillary anterior teeth. Bone density, another alveolar bone measurement, was reported to significantly decrease after extraction treatment in two studies.[14,23] However, Yu et al reported that reduced bone density returned to its original density after 2 years of retention.[40]

Similar to the lingual movement of anterior teeth during retraction, labial movement of anterior teeth in non-extraction cases also induced alveolar bone loss. Steiner et al showed that labial movement of mandibular incisors, by 3.05 mm, resulted in 5.48 mm of vertical bone loss in monkeys.[41] Our meta-analysis revealed vertical alveolar bone loss on both the labial (0.97 mm) and lingual sides (0.86 mm) of mandibular incisors. Regarding maxillary incisors, Maspero et al observed significant labial vertical bone loss in maxillary central incisors (0.5 mm), whereas lingual vertical bone changes were not significant.[28] Castro et al reported no significant changes in labial or lingual vertical bone levels in maxillary incisors, but there was significant labial vertical bone loss in maxillary canines.[31] Maxillary canines and mandibular incisors showed a high risk of vertical alveolar bone loss in non-extraction cases.

Diagnosis	Treatment Plan	Duration of observation	Alveolar bone measurement
Not mentioned	Extraction of four first premolars	T1: pre-treatment T2: 6 mo after orthodontic treatment	Measurement of bone density
Dental and Skeletal Class I	Extraction of four premolars	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone thickness and height
Dental Class II division I	Extraction of first maxillary premolars	T1: pre-treatment T2: post-treatment	Measurement of alveolar bone thickness

TABLE 4 Methodological index for non-randomized studies (MINORS)

Minors score														
Author	Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
Ahn et al	2016	2	0	0	2	2	2	0	0	1	2	2	2	15
Ma et al	2015	2	1	1	2	2	2	0	0	2	2	1	1	16
Picanço et al	2015	2	1	0	2	2	2	0	0	1	0	2	2	14
Ahn et al	2013	2	1	1	2	2	2	2	0					12
Castro et al	2016	2	0	0	2	2	1	0	0					7
Chang et al	2012	2	0	2	2	2	2	2	0					12
Chen et al	2018	2	1	0	2	2	2	0	0					9
Garlock et al	2016	2	0	0	2	2	2	0	0					8
Guo et al	2011	2	0	2	2	2	2	0	0					10
Lee et al	2012	2	0	0	2	2	2	0	0					8
Liu et al	2016	2	0	0	2	2	2	0	0					8
Maspero et al	2019	2	0	0	2	2	2	0	0					8
Matsumoto et al	2020	2	0	0	2	2	2	0	0					8
Morais et al	2018	2	1	1	2	2	2	1	2					13
Nayak et al	2013	2	0	0	2	2	2	0	0					8
Oliveira et al	2016	2	1	1	2	2	2	2	2					14
Sarikaya et al	2002	2	0	0	2	2	2	0	0					8
Sun et al	2015	2	0	0	2	2	2	0	0					8
Wang et al	2018	2	0	0	2	2	2	0	0					8
Yodthong et al	2013	2	0	0	2	2	2	0	0					8
Zasčiurinskienė et al	2019	2	1	1	2	2	2	2	2					14
Zhang et al	2015	2	0	0	2	2	2	0	0					8
Zhang et al	2019	2	0	0	2	2	2	0	0					8
Zhou et al	2018	2	0	0	2	2	2	0	0					8

Note: The item 1-12 represent: 1, a clearly stated aim; 2, inclusion of consecutive patients; 3, prospective collection of data; 4, endpoints appropriate to the aim of the study; 5, unbiased assessment of the study endpoint; 6, follow-up period appropriate to the aim of the study; 7, loss to follow-up less than 5%; 8, prospective calculation of the study size; 9, an adequate control group; 10, contemporary groups; 11, baseline equivalence of groups; and 12, adequate statistical analysis. The item scored 0 means not mentioned, 1 means reported but inadequate, and 2 means reported and adequate. The total score is 24 for cohort study, 16 for self-controlled study.

During labial movement of anterior teeth, the amount of initial crowding and the curve of Spee determine the proclination of anterior teeth, which influences alveolar bone remodelling. Among these six studies, two included patients with mild crowding, three included patients with mild to moderate crowding, and one did not report initial crowding. Unfortunately, the curve of Spee was not reported in all these studies.

Considering the initial bone thickness and height, we analysed skeletal class III patients separately. Vertical bone loss in mandibular incisors was 1.16 mm on the labial side and 0.83 mm on the lingual side. Regarding bone thickness in mandibular incisors, Lee et al reported that bone thickness at the mid-root level decreased at both the labial and lingual levels,[10] and Ahn et al reported a significant decrease in labial bone thickness at the upper and middle levels.[11]

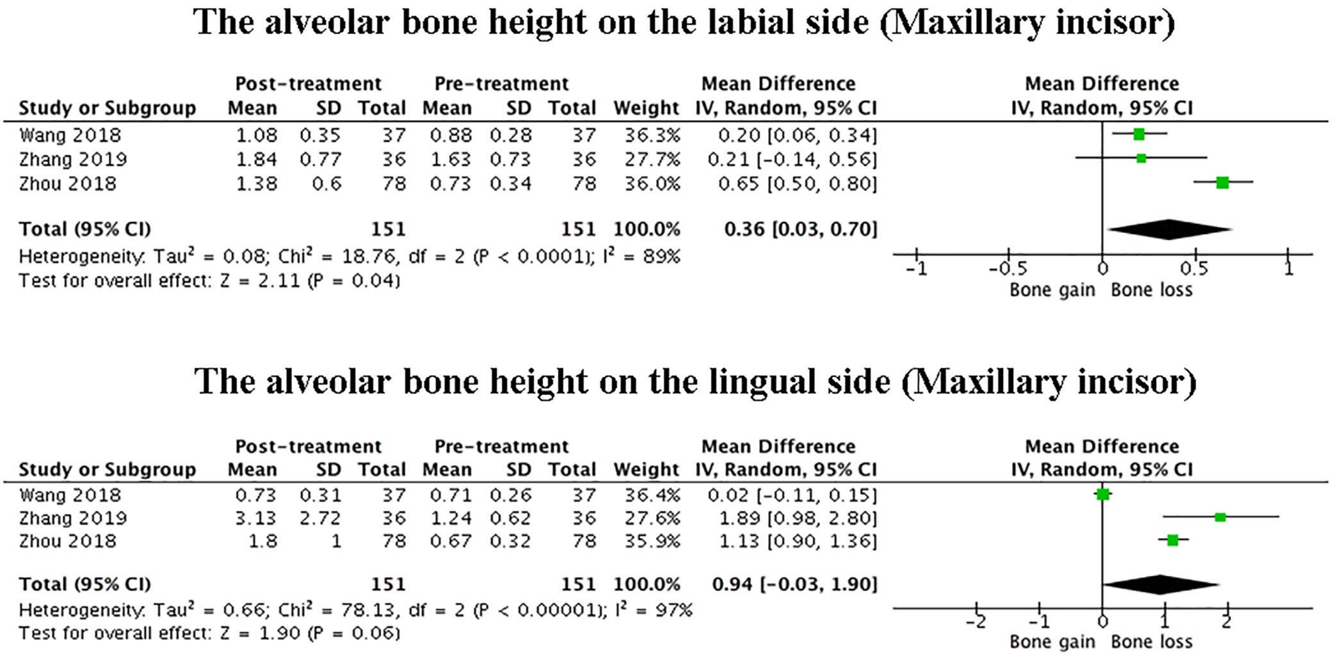

FIGURE 3 Forest plots of alveolar bone height changes in the maxillary incisors during extraction treatment [Colour figure can be viewed at wileyonlinelibrary.com]

However, for skeletal class III patients with a thin mandibular symphysis, even a small amount of bone loss can create a risk of periodontal destruction.

The repairability of alveolar bone after the retraction period remains controversial. In our subgroup analysis, the decrease in lingual bone thickness and the increase in labial bone thickness were obvious 1-3 months after retraction. However, these changes were less obvious after orthodontic treatment, indicating that bone regeneration is not stable after retraction. Some studies suggest that bone remodelling occurs continuously during the retention period.[10,14] Among these, Sarikaya et al showed that bone deposition took place after 4 months of retention, although it did not return to the original level.[14] In contrast, Ahn et al observed no spontaneous bone apposition after retraction.[6] Once the perforation occurred, no newly formed bone was noted during the retention period. Further studies are required to investigate alveolar bone changes during the retention period.

Based on the above results, both labial and lingual movement of anterior teeth could jeopardize periodontal health. However, periodontal surgery may be an alternative approach to avoid further periodontal destruction. Corticotomy is an efficient technique that reduces the treatment time and accelerates bone remodelling.[42] The regional acceleratory phenomenon induced by corticotomy surgery increases osteoblastic and osteoclastic activity. *En masse* retraction with corticotomy surgery and bone grafting has been shown to improve alveolar bone levels. Preeti et al conducted an RCT study showing a significant increase in alveolar bone thickness in a corticotomy group during upper maxillary incisor retraction.[42] Corticotomy with bone graft before tooth movement could decrease the risk of periodontal side effects.[12,43]

In patients with well-controlled periodontitis, alveolar bone changes during orthodontic treatment, including in bone height and thickness, were small. No significant difference was observed in mean alveolar bone levels before and after orthodontic treatment, according to Zasčiurinskienė et al[33] Regarding proclined maxillary incisors, intrusion and retraction help reposition the teeth so that they are upright in the basal bone, leading to alveolar bone gain. Interestingly, Puttaravuttiporn et al reported that biting exercises during orthodontic treatment increased alveolar bone thickness in patients with periodontitis.[35] Although all three included studies supported the safety of orthodontic treatment, the orthodontic treatment plans were not well reported in these studies. Only one study reported that internal enamel reduction was used to resolve crowding, and flared anterior teeth were intruded and retracted.[33] Proper force application and periodontal maintenance are required in periodontal-orthodontic treatment. Due to the limited number of included studies, further studies are required to verify the results of our meta-analysis.

4.1 | Limitations

The absence of high-quality studies was the main limitation of this systematic review and meta-analysis. Most of the included studies were retrospective uncontrolled studies, which have a high risk of bias. The remaining controlled studies did not include an untreated control group. Hence, only the orthodontic groups in these controlled studies were included in our meta-analysis. Without the untreated control group, the natural change in alveolar bone could not be eliminated. In addition, the insufficient number of studies limited the quantitative analysis of lateral incisors and canines.

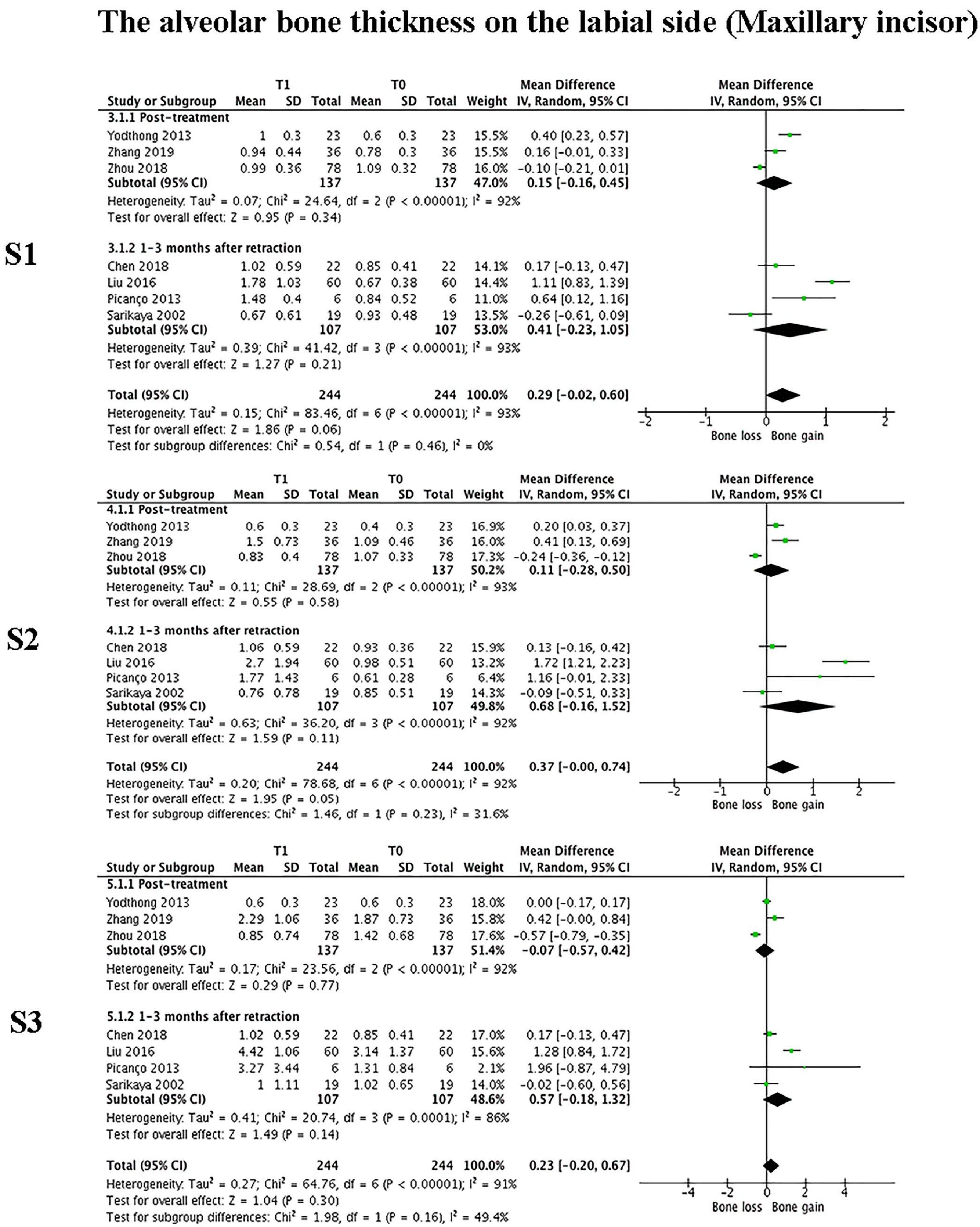

FIGURE 4 Forest plots of labial alveolar bone thickness changes in the maxillary incisors during extraction treatment [Colour figure can be viewed at wileyonlinelibrary.com]

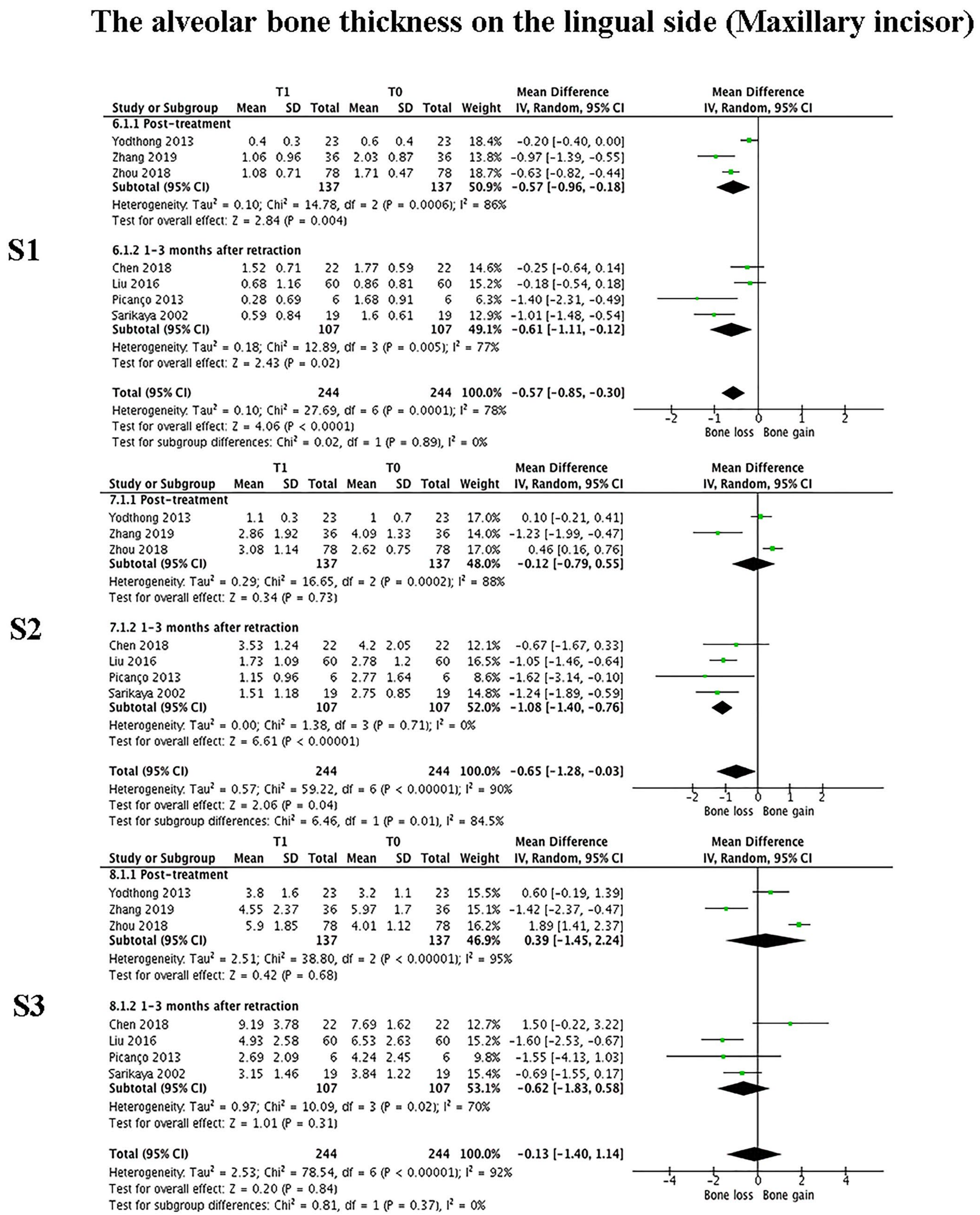

FIGURE 5 Forest plots of lingual alveolar bone thickness changes in the maxillary incisors during extraction treatment [Colour figure can be viewed at wileyonlinelibrary.com]

Another limitation was the high clinical heterogeneity of the included studies. Although subgroup analysis was performed to reduce the heterogeneity from different treatment durations, skeletal types, tooth movement directions and periodontal statuses, there were still several confounding factors in this systematic review. Orthodontic procedures are always accompanied by a risk of bias. Several factors,

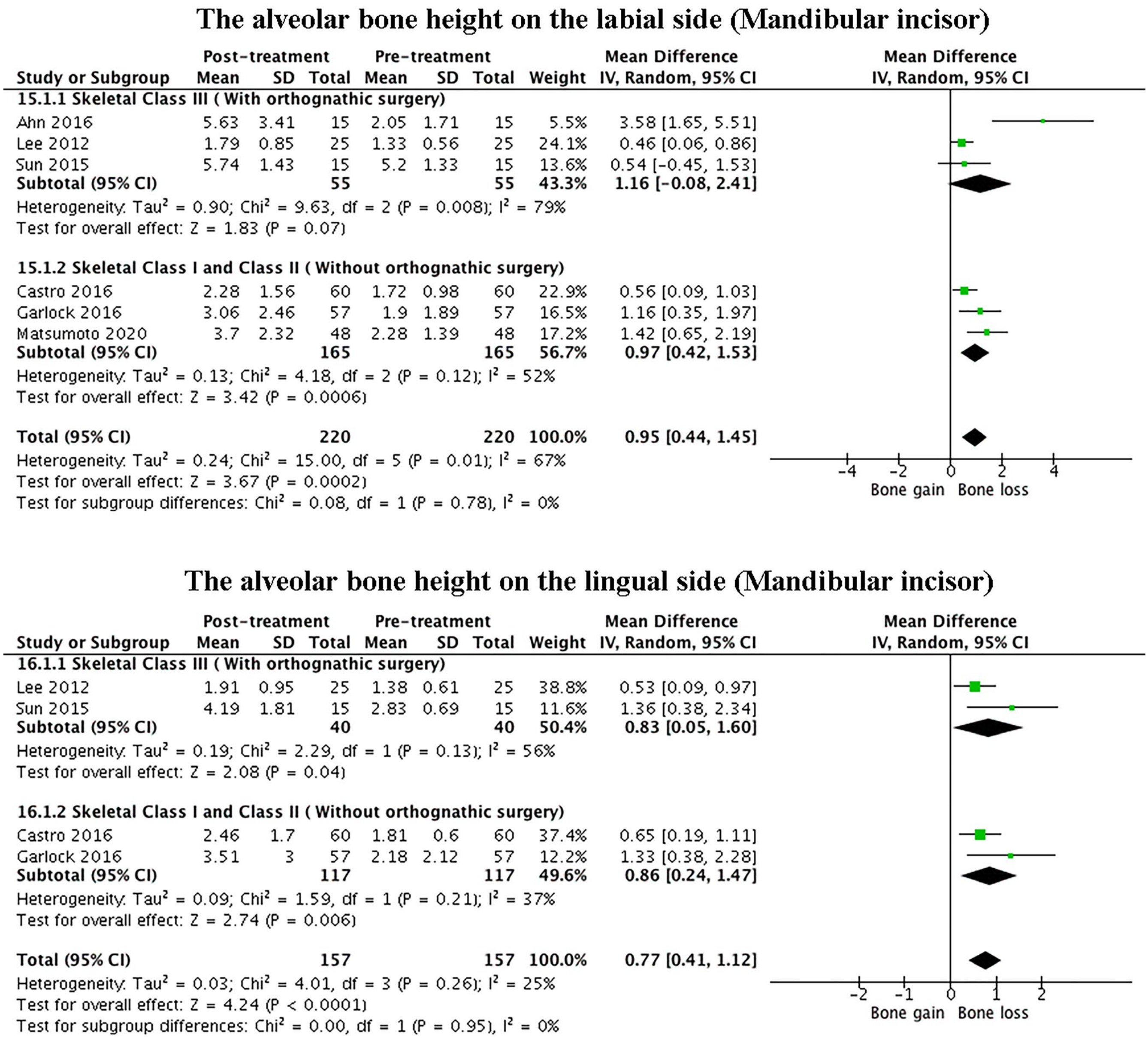

FIGURE 6 Forest plots of alveolar bone height changes in the mandibular incisors of non-extraction patients and skeletal class III patients [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 5 Quality of available evidence using GRADE

Outcome	Downgrade					Upgrade	Overall Quality
	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication Bias		
The alveolar bone height of maxillary incisor	Serious[a]	Serious[b]	Serious[c]	Serious[d]	None	None	Very low
The alveolar bone thickness of maxillary incisor	Serious[a]	Serious[b]	Serious[c]	Serious[d]	None	None	Very low
The alveolar bone height of mandibular incisor	Serious[a]	Serious[b]	Serious[c]	Serious[d]	None	None	Very low

[a]All studies were retrospective with a high risk of bias.

[b]Higher statistical heterogeneity was involved.

[c]Higher clinical heterogeneity limited the applicability to the general population.

[d]The participants included in meta-analysis were limited.

such as the amount and type of tooth movement and the magnitude of orthodontic forces, were generally not well reported. The original bone anatomy and initial tooth position should also be considered in bone remodelling. Unfortunately, limited information for these factors was provided in the included studies. Additionally, the angle classification in each subgroup was inconsistent, and the skeletal classification in most of the included studies was not reported. In addition, the age of the patients varied among these studies. Eleven studies included the growing patients, and 15 studies included adult patients. The growing patients have a greater bone remodelling ability, while adult patients show a greater amount of vertical bone loss during orthodontic treatment.[44]

Methodological heterogeneity was also noted in the present study. Most of the included studies measured bone thickness at three levels (cervical, middle and apical levels), while one study measured it at five levels from the cementoenamel junction to the apical apex,[23] and three studies measured it at two levels (mid-root and apex levels).[10,28,29] The inconsistent studies were excluded from the quantitative analysis and were only included in the qualitative analysis. Moreover, the voxel sizes and field of view of CBCT among the included studies were inconsistent, which could partially be attributed to methodological bias. In this review, the voxel sizes were typically 0.3-0.5 mm. Bone thickness less than 0.5 mm could be underestimated.[45]

The above factors cause the extent of data synthesis to be unsatisfactory. For these reasons, this systematic review and meta-analysis only reflects the general tendency towards changes in the alveolar bone level during orthodontic treatment. Further high-quality studies with larger samples are required.

5 | CONCLUSIONS

1. Alveolar bone height and thickness, especially at the cervical level, decreased during both labial and lingual movement of anterior teeth.
2. In extraction cases, bone remodelling is not stable after retraction. Both alveolar bone loss on the lingual side and alveolar bone gain on the labial side were obvious 1-3 months after retraction but were less obvious after orthodontic treatment.
3. In non-extraction cases, maxillary canines and mandibular incisors showed a high risk of alveolar bone loss.
4. Alveolar bone loss in mandibular incisors should be specially considered in skeletal class III patients.
5. For patients with periodontitis, alveolar bone changes during orthodontic treatment were small and low risk.

Based on limited evidence, these results should be interpreted with caution and evaluated with further high-quality studies with long-term observation.

CONFLICT OF INTEREST

None to declare.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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