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Review Article

The impact of different activation protocols of rapid maxillary expansion on external root resorption: a systematic review and meta-analysis

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Abstract: This comprehensive meta-analysis investigated the effects of Rapid Maxillary Expansion (RME) on external root resorption, which is a prevalent orthodontic treatment intended to correct transverse maxillary deficiency and constricted dental arches. By conducting a systematic literature search across prominent electronic databases, including the Cochrane Library, EMBASE, LILACS, MEDLINE, PubMed, and Web of Science, the study compiled evidence until April 2023. A spectrum of search terms was utilized to capture diverse aspects of root resorption, RME, palatal expansion methods, and tooth erosion. Registered with INPLASY (202430057), the meta-analysis meticulously screened 11 studies that fulfilled stringent inclusion criteria. The quality of these studies was assessed using the Cochrane Bias Risk Assessment Tool for Randomized Controlled Trials (RCTs) and the Methodological Index for Non-Randomized Studies (MINORS) for other research designs. The collective analyses disclosed a substantial impact of RME on external root resorption, indicating that the treatment may induce pronounced root erosion. Subgroup analyses further elucidated distinct patterns in root resorption among various types of RME, underscoring the variability in treatment outcomes and the need for personalized care. Consequently, the meta-analysis unequivocally confirmed that external root resorption may be a concerning consequence of RME treatment, necessitating thorough monitoring and management strategies to mitigate potential adverse effects on dental health.

Keywords: Rapid maxillary expansion, external root resorption, meta-analysis, orthodontic treatment

Introduction

External root resorption (ERR) is an inflammatory reaction that usually occurs in orthodontic therapy, and its causes are complex [1]. ERR is problematic as it can have long-term effects on the health of the teeth [2]. The etiology of ERR is multifactorial, involving individual biological variability, genetic predisposition, and the influence of mechanical factors [3]. ERR is a complex sterile inflammatory process that involves various components such as forces, tooth roots, bone, cells, surrounding matrix, and specific biological messengers [4]. ERR can be classified into surface, inflammatory, and replacement root resorption (RR) [5]. The progression and clinical significance vary among the different types of RR. ERR possibly leads to widespread tooth devastation, causing tooth loss [6]. Although ERR can occur in any tooth, it often affects the maxillary incisors [7].

Rapid maxillary expansion (RME), also known as rapid palatal expansion (RPE), was primarily depicted by Vali et al. and remains an intrinsic part of orthodontic treatment methods nowadays [8]. RME is commonly used as a standard medical technique, aiming to routinely separating the palatine suture with transverse expansion of the maxilla, creating a wider palatal arch, and correcting posterior crossbite [9]. Currently, the main types of RME are tooth-borne (TB), tooth-tissue-borne (TTB), and bone-borne (BB) [10]. Hyrax is the most used TB RME, and Haas is the most used TTB RME in the clinic [11]. BB RME is rarely used in clinics because of its severe trauma. Tooth-bone-borne (TBB) is a modified RME with microscrew

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Table 1. Inclusion criteria employed for literature selection

Aspect	Contents
Study type	RCTs, non-RCTs, cohort studies, CCSs, before-and-after studies.
Research objects	In patients with narrow upper dental arch and transverse underdevelopment, the first premolars and first molars have erupted in mixed or permanent dentition.
Interventions	RME vs. un-expansion, self-comparison of RME, comparison of different kinds of RME.
Outcome indicators	The tooth-root length, volume, and linear surface changes were measured by cone-beam computed tomography (CBCT).

RCTs: Randomized controlled trials; CCSs: Case-control studies.

implant anchorage to achieve therapeutic effect of BB [12]. Compared with traditional RME, TBB and BB are considered to have better osseous development effects and less dental development effects [13]. However, studies are needed to provide comparative data on root resorption following RME with TB and BB expanders.

In this review, we aimed to explore the root resorption of patients treated with RME and compare the root resorption in patients treated with different RMEs to provide a more scientific basis for clinical practice.

Methods

The protocol was settled based on the Cochrane Handbook16 for systematic review [14] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) declaration [15]. The Meta-analysis was registered at INPLASY (International Platform of Registered Systematic Review and Meta-Analysis Protocols, 202430057).

Inclusion and exclusion criteria

The inclusion criteria for eligible articles in this meta-analysis: 1) random controlled trials (RCTs), non-RCTs, cohort studies, case-control studies (CCSs), before-and-after studies; 2) studies involving patients with narrow upper dental arch and transverse underdevelopment, with the first premolars and first molars being erupted in mixed or permanent dentition; 3) studies involving comparison of RME vs. un-expansion, self-comparison of RME, or different kinds of RME; 4) studies with measured tooth-root length, volume, and linear surface changes by cone-beam computed tomography (CBCT) are as documened in **Table 1**.

We excluded studies with incomplete or missing analytic data, investigated people who had previously received orthodontic treatment, or in languages other than English. Besides, Reviews, case reports, and conference abstracts were not considered eligible.

Literature review

Electronic databases, including the Cochrane Library, EMBASE, LILACS, MEDLINE, PubMed, and Web of Science, were retrieved for relevant articles. The retrieved formula ((Root Resorption OR Root Resorptions OR Resorption, Root) AND (Rapid Maxillary Expansion OR Palatal Expansion Techniques OR RME OR Palatal Expansion Technic) AND (Erosion OR shortening OR blunting OR length)) was used to encompass any publications including the following search keywords: 'Root Resorption', 'Root Resorptions', 'Rapid Maxillary Expansion', 'Palatal Expansion Techniques', 'Palatal Expansion Technic', 'Erosion', 'shortening', 'blunting', and 'length'. All randomized controlled, case-control, non-randomized controlled, and before-and-after studies until April 2023 were included.

Data extraction and quality assessment

Two investigators (MW and DHM) individually assessed the literature quality and extracted data from the included articles. In cases of disagreement, the supervisor (XY) resolved the conflict and reached a final decision. Data extraction included first author, publication year, country, study region, objects of research, interventions, outcome indicators, and measuring time. The Cochrane Bias Risk Assessment Tool [16] was used to assess the bias of RCTs, while the methodological index for non-randomized studies (MINORS) [17] was used for

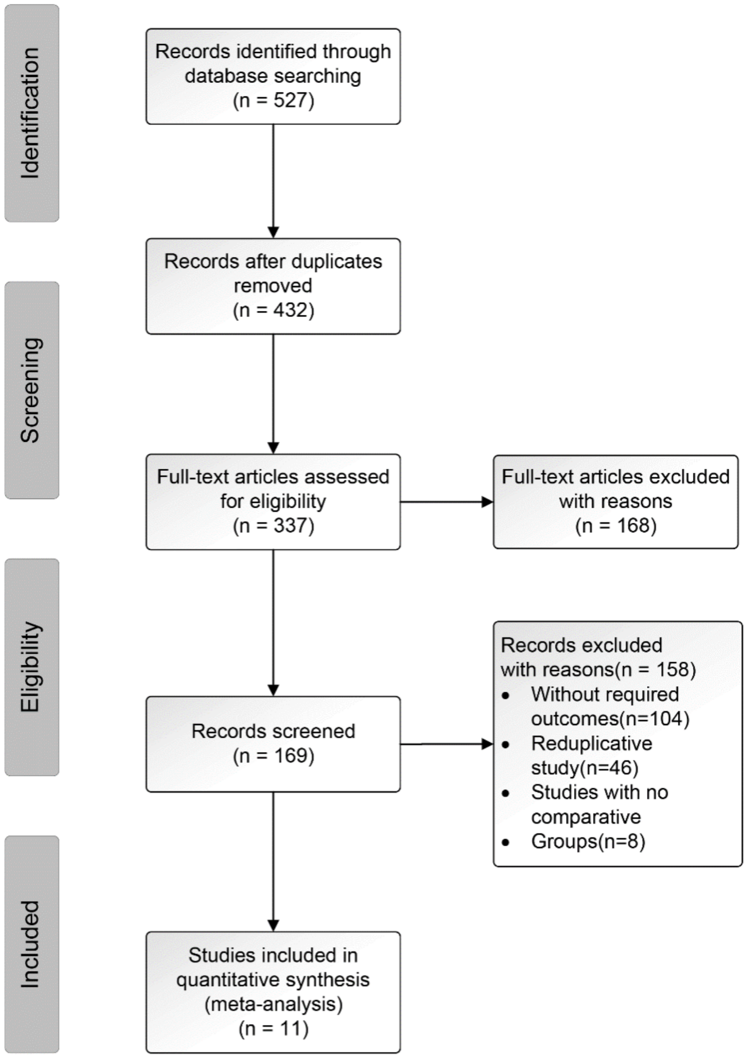

Figure 1. Flow chart of the literature selection process.

other studies. Articles of poor quality would be eliminated from this meta-analysis.

Statistical analysis

All statistical analyses were carried out using RevMan 5.3 software (The Cochrane Collaboration). Differences in outcome indicators were expressed as mean difference (MD) with pertinent 95% confidence interval (CI). These MDs were complemented by their corresponding 95% CIs, which provide a measure of the precision and reliability of the estimated effect. Heterogeneity among papers was measured through χ^2 based Q-test with I^2 statistic, which quantifies the percentage of total variation across studies that is due to heterogeneity rather than chance. It ranges from 0% to 100%, with higher values indicating greater heterogeneity. The sensitivity analysis was conducted to recognize influential cases with apparent heterogeneity.

Results

Literature selection

A total of 527 studies were obtained using the retrieval criteria. After eliminating 95 duplicates, we screened 432 studies based on their title and abstract. Then, 337 studies were screened after full text browsing. Subsequently, 168 were eliminated due to the following causes: 1) no required outcome or intervention in the article (n = 86); 2) study objective not matched (n = 42); 3) Inacceptable reference standard approach (n = 40). As a result, 11 studies were included in the final meta-analysis. **Figure 1** illustrates the flow of literature selection according to the PRISMA guidelines.

General characteristics

Eleven included studies were carried out in five countries (Brazil, United States, Korea, Italy, Germany, and Turkey) and were published in English between 2012 and 2022 (**Table 2**). The 11 studies included 348 participants randomized into experimental or control groups. Among the 348 patients, 137 (43.10%) were male. The characteristics of each study are listed in **Table 2**.

Quality evaluation of included studies

The quality evaluation was performed using the items for assessing randomized control trials with the Cochrane bias risk assessment tool. As shown in **Table 3**, most articles exhibited high methodological quality. Moreover, the quality evaluation was performed using the items for assessing non-random intervention studies with MINORS. As shown in **Table 4**, most articles showed high methodological quality.

Table 2. The general characteristics of each eligible study in this meta-analysis

Study (year)	Country	Study design	Objects	Interventions	Outcome indicators	Measuring time
Celenk-Koca et al. [21] (2018)	Turkey	RCT	BB: n = 20 (M = 7, F = 13) TB: n = 20 (M = 8, F = 12)	BB vs. TB	① ③	Before arch expansion & after retention
Dindaroğlu et al. [26] (2016)	Turkey	RCT	TTB: n = 17 (M = 9, F = 8) TB: n = 16 (M = 8, F = 8)	TTB vs. TB	②	Before arch expansion & after active arch expansion
Kayalar et al. [22] (2016)	Turkey	RCT	TBB: n = 10 (M = 3, F = 7) TB: n = 10 (M = 6, F = 4)	TBB vs. TB	①	Before arch expansion & after active arch expansion
Lemos et al. [27] (2018)	Brazil	RCT	TTB: n = 11 (M = 2, F = 9) BTB: n = 18 (M = 7, F = 11)	TTB vs. BTB	①	Before arch expansion & after active arch expansion
Yildirim et al. [28] (2019)	Turkey	Non-RCT	TTB: n = 16 (M = 6, F = 10) BTB: n = 18 (M = 7, F = 11)	BTB vs. TTB	②	Before arch expansion & after retention
Akyalcin et al. [25] (2015)	United States	Cohort study	TB: n = 24 (M = 13, F = 11) BB: n = 20 (M = 6, F = 14)	TB vs. BB	① ② ③	Before arch expansion & after retention
Baysal et al. [29] (2012)	Turkey	Self-control study	n = 25 (M = 11, F = 14)	Before and after TB	②	Before arch expansion & after active arch expansion
Kunz et al. [23] (2016)	Germany	RCT	BB: n = 16 (M = 6, F = 10) TB: n = 12 (M = 7, F = 5)	BB vs. TB	①	Before arch expansion & after retention
Lin et al. [11] (2014)	Korea	RCT	BB: n = 15 (M = 7, F = 8) TB: n = 13 (M = 8, F = 5)	BB vs. TB	① ②	Before arch expansion & after retention
Altieri et al. [30] (2021)	Italy	Cohort study	BB n = 12 (M = 7, F = 5) TB n = 20 (M = 8, F = 6)	BB vs. TB	① ③	Before arch expansion & after active arch expansion
Mehta et al. [31] (2022)	United States	RCT	TTB: n = 20 (M = 7, F = 13) BTB: n = 15 (M = 7, F = 8)	BTB vs. TTB	②	Before arch expansion & after retention

RCT: randomized control trial; M: male; F: female; TB: tooth-borne; TTB: tooth-tissue-borne; BB: bone-borne; BTB: borne-tooth-borne. ①: root length amelioration; ②: root volume amelioration; ③: linear surface area amelioration.

Table 3. Cochrane evaluation for included RCTs

Study	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Celenk-Koca et al. [21] (2018)	Low	Low	Low	Low	Low	Low	Low	High quality
Dindaroğlu et al. [26] (2016)	Unclear	Low	Low	Unclear	Low	Unclear	Low	Medium quality
Kayalar et al. [22] (2016)	Low	Low	Low	Low	Low	Unclear	Low	High quality
Lemos et al. [27] (2018)	Low	Low	Unclear	Low	Low	Low	Low	Medium quality
Kunz et al. [23] (2016)	Low	Low	Low	Low	Low	Unclear	Low	High quality
Lin et al. [11] (2014)	Low	Low	Low	Unclear	Low	Low	Low	High quality
Mehta et al. [31] (2022)	Low	Low	Low	Low	Low	Low	Low	High quality

Table 4. MINORS evaluation for included non-RCTs

Study	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Yildirim et al. [28] (2019)	Low	Low	Low	Low	Low	Low	Low	High quality
Akyalcin et al. [25] (2015)	Low	Low	Low	Low	Low	Unclear	Low	Medium quality
Baysal et al. [29] (2012)	Low	Low	Low	Low	Low	Low	Low	High quality
Altieri et al. [30] (2021)	Low	Low	Low	Low	Low	Low	Low	High quality

Comparison of ERR before and after tooth-borne RME treatment

Three articles reported root resorption from before accepting RME to after active arch expansion (before retention). The results of our meta-analysis showed that the root resorption was significantly distinct before and after active arch expansion (before retention) (MD = 0.3786, 95% CI [0.2296, 0.5276], P < 0.00001, **Figure 2**).

Two articles reported the root length from before TB RME to after active arch expansion

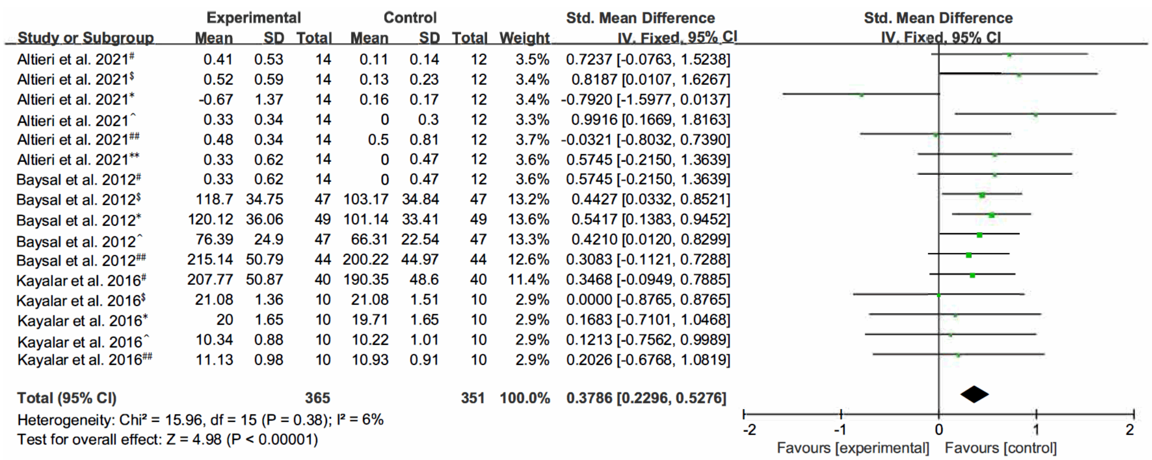

Figure 2. The root resorption before RME vs. after active arch expansion. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. RME: Rapid Maxillary Expansion.

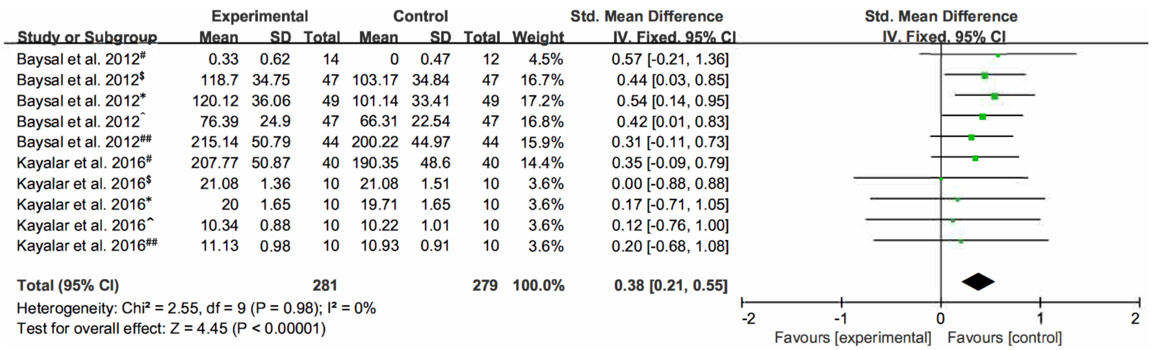

Figure 3. The root length before RME vs. after active arch expansion. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. RME: Rapid Maxillary Expansion.

(before retention). The results showed that compared with before tooth-borne RME, the root resorption was pronounced, and the length was reduced by 0.38 mm after active arch expansion (before retention) (MD = 0.38 mm, 95% CI [0.21, 0.55], P < 0.00001, **Figure 3**).

Four articles reported the root length from before TB RME to after retention. The results showed that compared with before tooth-borne RME, the root resorption was evident, and the length was reduced by 0.39 mm after retention (MD = 0.33 mm, 95% CI [0.22, 0.45], P < 0.00001, **Figure 4**).

Comparison of ERR before and after bone-borne RME treatment

Five articles reported the root length from before RME to after retention. The results showed that compared with before tooth-borne RME, the root resorption was evident, and the length was reduced by 0.27 mm after RME (MD = 0.27 mm, 95% CI [0.16, 0.39], P < 0.00001, **Figure 5**).

Comparison of ERR between bone-tissue-borne and tooth-tissue-borne RME

Three articles described TTB and BTB RME. The results showed that no differences in root resorption were observed between bone-borne RME and tooth-issue-borne RME (MD = 0.56 mm, 95% CI [0.38, 0.73], P = 0.13, **Figure 6**).

Comparison of ERR between bone-borne and tooth-borne RME

Three articles described bone-borne and tooth-borne RME. The results showed that no differences in root resorption were observed between bone-borne RME and tooth-issue-

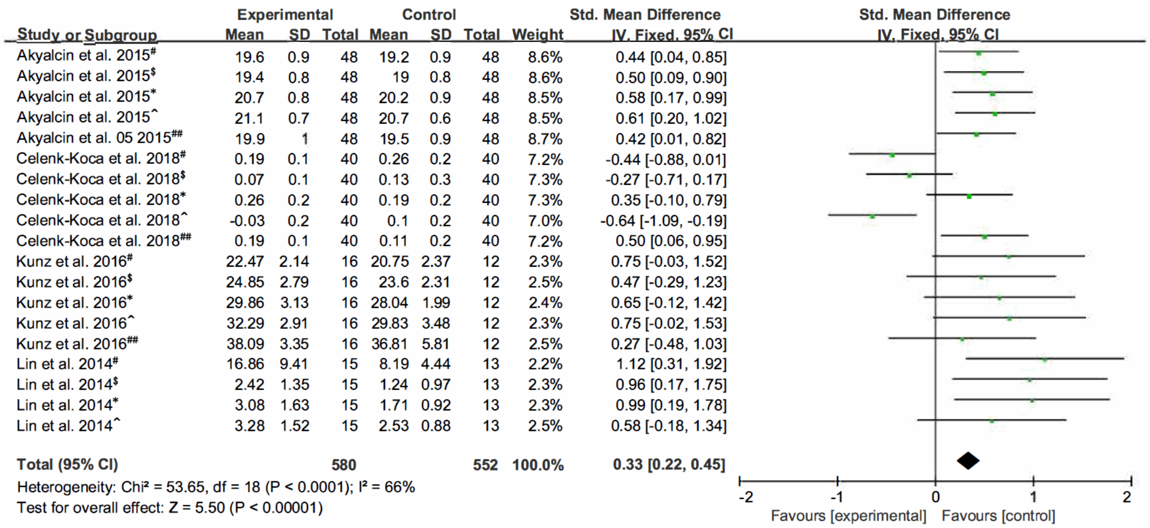

Figure 4. The root length before RME vs. after retention. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. RME: Rapid Maxillary Expansion.

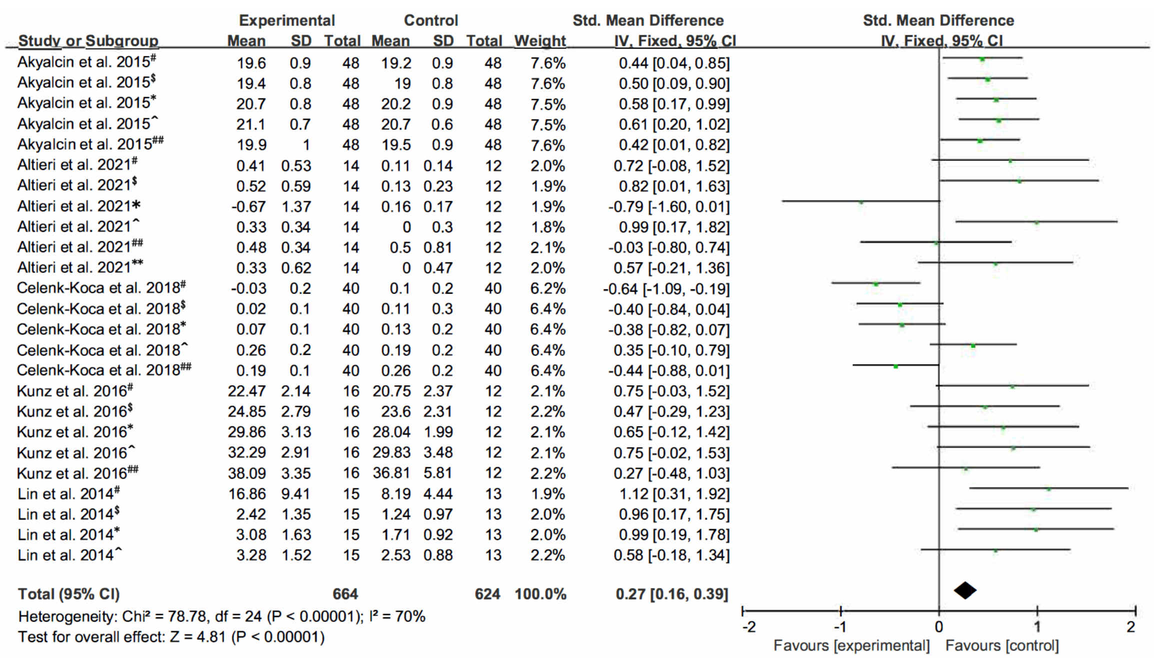

Figure 5. Comparison of ERR before and after bone-borne RME treatment. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. ERR: External root resorption; RME: Rapid Maxillary Expansion.

borne RME (MD = 0.20 mm, 95% CI [0.05, 0.36], P < 0.00001, **Figure 7**). After sensitivity analysis and removal of the primary sources of heterogeneity, the difference was statistically significant (MD = -0.26 mm, 95% CI [-0.42, -0.10], P < 0.00001, **Figure 8**).

Publication bias

Funnel plot was employed to detect the potential publication bias. No significant publication bias was observed by funnel plots (**Figure 9**) and Begg's test (all P > 0.05).

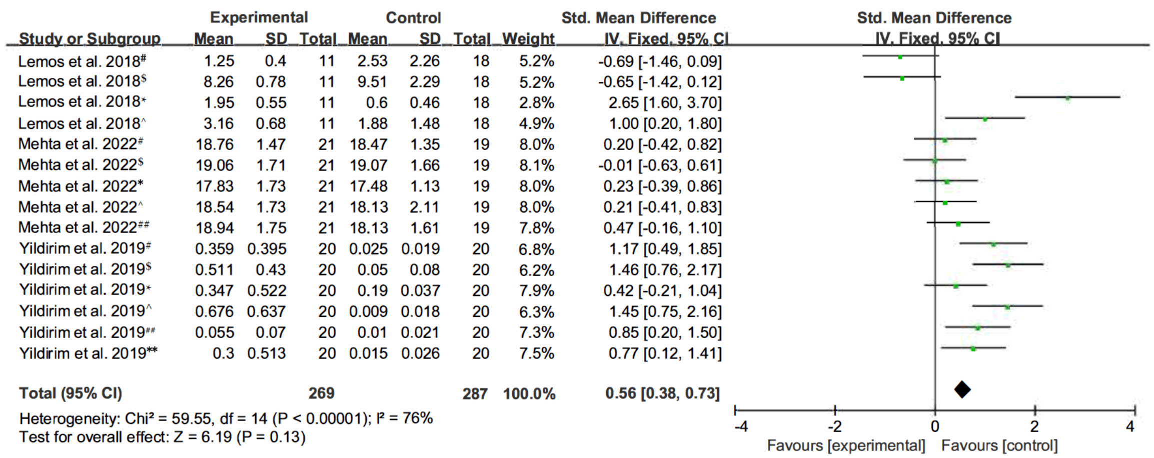

Figure 6. Comparison of ERR between bone-tissue-borne and tooth-tissue-borne RME. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. ERR: External root resorption; RME: Rapid Maxillary Expansion.

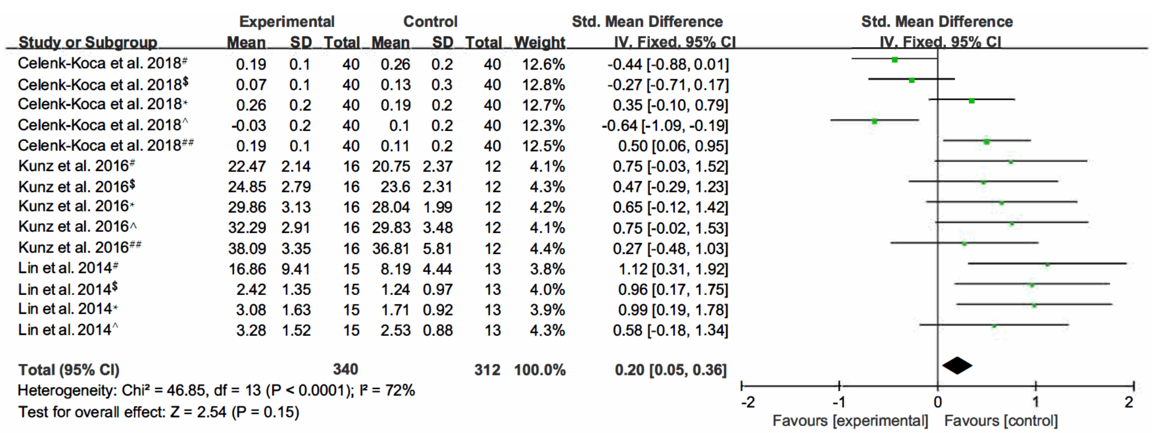

Figure 7. Comparison of ERR between bone-borne and tooth-borne RME. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. ERR: External root resorption; RME: Rapid Maxillary Expansion.

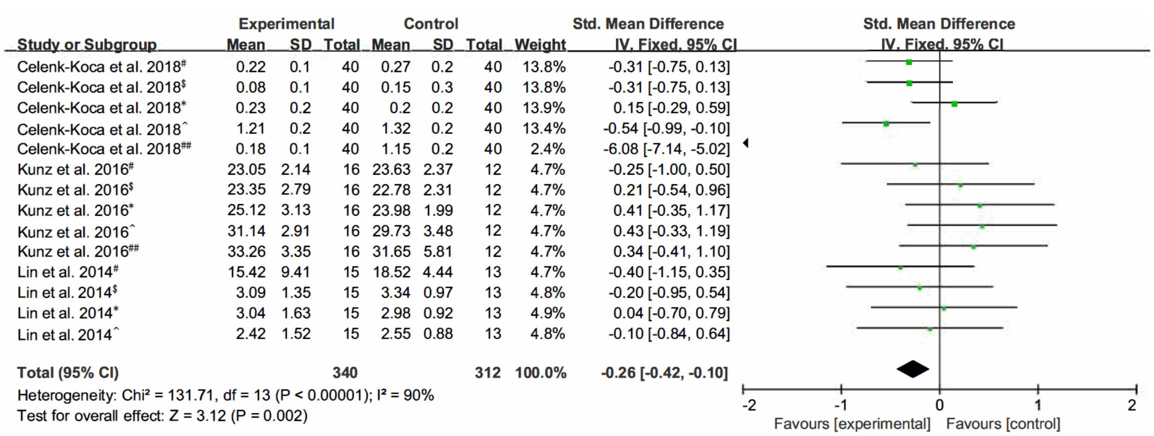

Figure 8. Comparison of ERR between bone-borne and tooth-borne RME after sensitivity analysis. #: First molar palatal root; $: First molar mesiobuccal root; *: First molar distobuccal root; ^: Second premolar; ##: First premolar; **: First molar mesiolingual root. ERR: External root resorption; RME: Rapid Maxillary Expansion.

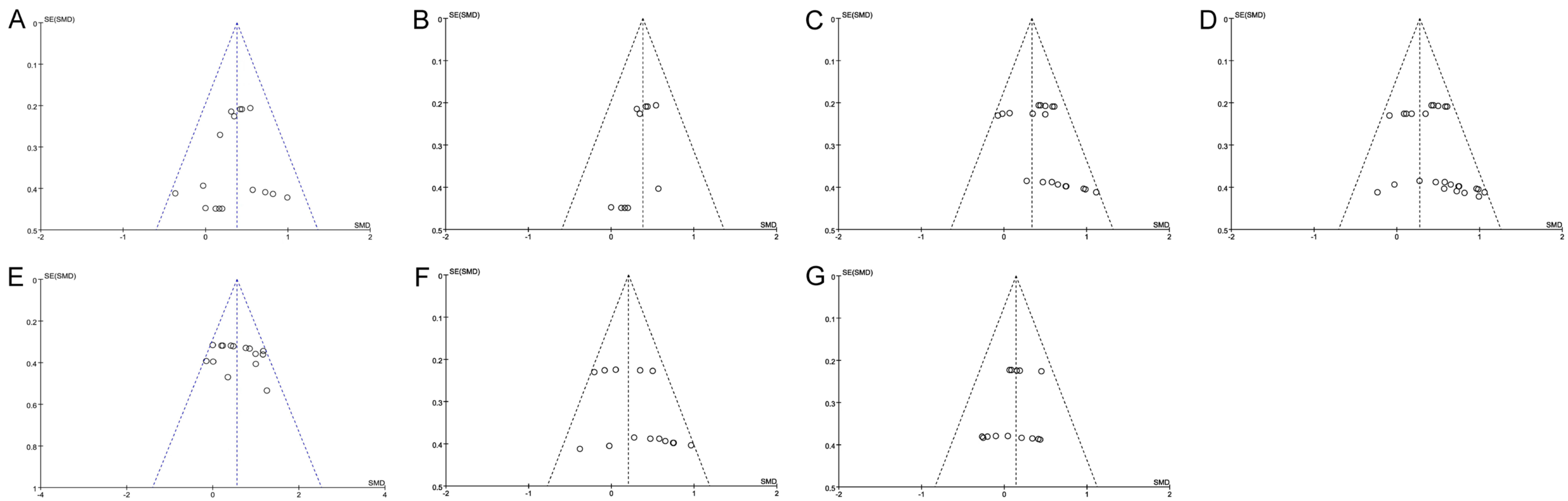

Figure 9. Publication bias assessment. A. Publication bias for root resorption before RME vs. after active arch expansion; B. Publication bias for root length before RME vs. after active arch expansion; C. Publication bias for root length before RME vs. after retention; D. Publication bias for comparison of ERR before and after bone-borne RME treatment; E. Publication bias for comparison of ERR between bone-tissue-borne and tooth-tissue-borne RME; F. Publication bias for comparison of ERR between bone-borne and tooth-borne RME; G. Publication bias for comparison of ERR between bone-borne and tooth-borne RME after sensitivity analysis. ERR: External root resorption; RME: Rapid Maxillary Expansion.

Sensitivity analysis

The sensitivity analysis was carried out to determine how sensitive the results were to changes in the assumptions or methods used. Sensitivity analysis indicated low sensitivity and high stability of this meta-analysis.

Discussion

Tooth-borne Rapid Maxillary Expansion (RME) is a commonly used orthodontic treatment for maxillary transverse deficiency, where the expander is anchored to the teeth using bands or attachments. This method has been associated with variable degrees of root resorption [18]. In our meta-analysis, we included studies that compared the degree of root resorption in patients treated with tooth-borne RME to those treated with bone-borne RME, including tooth-tissue-borne support and tooth-bone-borne support. We found that the overall degree of root resorption was higher in tooth-borne RME compared to bone-borne RME. Specifically, studies comparing tooth-tissue-borne support and tooth-bone-borne support RME showed that tooth-tissue-borne support resulted in higher levels of root resorption compared to tooth-bone-borne support. This may be because that tooth-tissue-borne expanders exert more force on the teeth, leading to increased stress and potential root resorption.

The use of a tooth-borne device for RME is a common choice in orthodontic treatment. However, there are potential drawbacks associated with tooth-borne expanders. When a tooth-borne retractor is fixed on the teeth, it exerts a large force on the periodontal tissue and alveolar bone during the expansion process. This excessive force can lead to several issues, including buccal tilt of the anchored teeth, outward rotation of the palatal segment, buccal root exposure, and periodontal problems. The buccal tilt of the teeth can affect the overall alignment of the dentition and may result in a less stable and optimal occlusion. The outward rotation of the palatal segment can impact the overall shape and position of the upper jaw, potentially leading to changes in facial aesthetics. Additionally, buccal root exposure may occur because of the expansion forces exerted by the tooth-borne device, which leads to root resorption and potential damage to the tooth structure. Periodontal problems, such as gum recession or inflammation, may also arise due to the stress placed on the supporting tissues surrounding the teeth [19].

In this meta-analysis, three articles reported root resorption from before accepting RME to after active arch expansion (before retention). The results of our meta-analysis showed that the root resorption was significantly distinct before and after active arch expansion (before retention) (MD = 0.3786, 95% CI [0.2296, 0.5276], $P < 0.00001$). Two articles reported the root length from before TB RME to after active arch expansion (before retention). The results showed that compared with before tooth-borne RME, the root resorption was pronounced, and the length was reduced by 0.38 mm after active arch expansion (before retention) (MD = 0.38 mm, 95% CI [0.21, 0.55], $P < 0.00001$).

To avoid the complications caused by TB, a bone-borne (BB) device is introduced, which transfers force directly to the palatine bone, reducing tooth inclination and root resorption [20]. However, the BB distractor is expensive, requires a second operation to remove, and there is a risk of root disease or infection, asymmetric dilatation, and periodontal injury. Four articles involved root resorption treated with bone-borne support RME, all of which were of high quality. One article showed that the root resorption of the first premolar was not evident, while the root resorption of the first molar was evident [21]. One article only measured the first molar. The results showed that the root resorption was pronounced [22]. Kunz et al. [23] found that the two types of distractors can cause different degrees of dental arch expansion and buccal crown tilt, with different expansion modes. TB distractor can lead to parallel expansion, while BB distractor can lead to V-shaped dilatation [24]. Kayalar et al. [25] indicated that the TBB distractor could reduce tooth inclination and root resorption compared with TB, with better clinical effect. TB and BB distractors have their own advantages and disadvantages, and further research is needed to determine their applicability. In contrast, the advantages of TBB distractors are obvious, providing more options for RME treatment. Orthodontic professionals must carefully consider these potential complications when choosing a tooth-borne device for RME treatment. Alternative methods, such as bone-borne expanders, may be considered to minimize the negative effects on the teeth and supporting structures. Regular monitoring and follow-up care are essential to address any issues that may arise during the RME treatment process.

In addition, the combined results of our meta-analysis showed that root resorption was pronounced after tooth-bone-borne RME. Three articles described TTB and BTB RME. The results showed no differences in root resorption between bone-borne RME and tooth-issue-borne RME. Three articles described bone-borne and tooth-borne RME. The results showed that no differences in root resorption were observed between bone-borne RME and tooth-issue-borne RME. After sensitivity analysis and removal of the primary sources of heterogeneity, we observed a significant difference in root resorption between the two kinds of RME, and the root resorption of bone-borne RME was significantly less than that of tooth-borne RME. Interestingly, there were no significant differences in root resorption between bone-borne RME and tooth-tissue-borne RME. This suggests that while both types of expansion methods can lead to root resorption, the degree of resorption may not differ significantly between them. A recent study reviewed the mechanisms of root resorption after tooth-bone-borne RME, focusing on the influence of different activation protocols on the surrounding tissues and oral environment [12]. Moreover, another study explored the effects of different activation protocols on root resorption in rapid maxillary expansion. The author compared different types of RME and evaluated their impacts on root resorption [18]. Compared with other studies, our study has shown that tooth-bone-borne RME may be associated with a significant increase in root resorption. However, based on the findings of other studies, there is no significant difference in root resorption between bone-borne RME and tooth-tissue-borne RME. This may indicate that other factors such as individual differences, treatment duration, and operator experience may play a role in root resorption after RME. Additionally, our study found that there is no significant difference in root resorption between bone-borne RME and tooth-bone-borne RME. This may suggest that factors relating to the activation protocol are not the only determinants of root resorption after RME, but other factors such as patient factors and treatment conditions may also contribute to root resorption. These findings have important implications for orthodontic treatment planning and patient care. Orthodontic professionals should be aware of the potential of root resorption following RME treatment, particularly with tooth-bone-borne expanders. Close monitoring of patients, regular follow-up appointments, and appropriate treatment interventions may be necessary to address any root resorption issues that arise during or after RME treatment. Further research is needed to better understand the factors influencing root resorption in different types of RME treatment and to develop strategies to minimize this potential complication. By improving our understanding of root resorption mechanisms and risk factors, we can provide more effective and safer orthodontic treatment for our patients.

Overall, our meta-analysis suggests that bone-borne RME, including tooth-bone-borne support, may be a better option for patients who are concerned about root resorption. However, more research is needed to confirm these findings and determine the long-term effects of different types of RME on root resorption. Inevitably, this study has some limitations. All the included studies used Cone Beam Computed Tomography (CBCT) to measure root resorption. CBCT is considered to exhibit changes in root length and volume accurately, but the resolution affects the reliability of CBCT. The accuracy of measurement may be one of the reasons affecting heterogeneity. In addition, root resorption can occur on the surface of each position of the tooth root, leading to a volume change. Therefore, the outcome index included in the study will be more accurate if defined as a change in root volume. The change in root length affects the crown-root ratio, which is of particular significance to the prediction of tooth stability.

In conclusion, this meta-analysis systematically reviewed the literature about the relationship between RME and root resorption. The results showed that evident root resorption occurrs after TB support, TTB support, and BB RME treatment. Compared with TB support RME, BB support did not significantly reduce root resorption. This suggests that root resorption is a potential complication associated with RME treatment, regardless of the method of support used. The forces exerted during the expansion process can lead to root resorption, which may have implications for the long-term health and stability of the teeth. Orthodontic professionals should be aware of the risk of root resorption when considering RME treatment for patients and should closely monitor for any signs of resorption during and after treatment. Further research is necessary to better understand the mechanisms of root resorption following RME treatment and to develop strategies to minimize its occurrence.

Disclosure of conflict of interest

None.

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