Review

Root resorption factors associated with orthodontic treatment with fixed appliances: A systematic review and meta-analysis

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Conflict of interest
None declared

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Abstract

External apical root resorption (EARR) is a serious complication that should be avoided during orthodontic treatment; this pathology depends on multiple factors. Data from clinical studies should be assessed to determine the influence these factors have on the development of EARR. This systematic review aims to compare EARR produced by different factors (orthodontic systems, dental trauma, and dental vitality). The protocol was registered on the PROSPERO database. The search was performed on 5 databases. Accepted study designs included randomized controlled trials, nonrandomized clinical trials, and observational studies. Full-text articles from clinical studies of EARR associated with orthodontic treatment in English, Spanish, or Portuguese with no publication date restrictions were selected. Data from the studies, such as age, population, study groups, and outcome measures, were recorded. Multiple meta-analyses were performed with data from the included studies. Evidence suggests that EARR induced by orthodontic treatment is similar, regardless of the technique used. Evidence of the effect of previous dental trauma on EARR during orthodontic treatment is limited. There is less EARR associated with orthodontic treatment in endodontically treated teeth than in vital teeth. These conclusions should be considered with caution due to the low certainty of the evidence.

Keywords: root resorption factors, external apical root resorption, self-ligating brackets, conventional brackets

Introduction

Orthodontic treatment can lead to complications such as external apical root resorption (EARR),[1] tooth loss,[2] dental fractures,[3] root exposure,[4] demineralization,[5] white spots on the enamel,[6] early closure of the apex,[2] pulpitis,[7,8] periodontal disease,[9] bone resorption,[10] traumatized soft tissues,[11] temporomandibular joint dysfunction,[12] and condylar resorption.[13,14] Individual factors such as short roots and trauma can predispose the patient to these complications.[15,16]

Root resorption (RR) is a serious complication that should be avoided during orthodontic treatment. This pathology depends on multiple factors, including: 1) factors specific to the patient, such as genetics (interleukin (IL)-1β polymorphism),[17] age and gender,[18] personal habits,[2,19] shape of the root,[10] systemic factors,[20] periodontal disease,[21–23] occlusal relationship,[24,25] dental morphology,[26] dental size,[27] traumatized teeth,[28] periapical infection,[29] and previous root resorption[15]; and 2) factors related to orthodontic treatment,[30] such as inadequate biomechanics,[31] long duration of treatment,[32] type of orthodontic movements,[33] intensity of the forces,[34] range of movements, and type of orthodontic appliances.[35] The mandibular and maxillary incisors have been reported as the teeth most susceptible to RR due to orthodontic treatment[36]; therefore, the orthodontist should consider determining factors for proper management during orthodontic treatment.[37] Root resorption can be classified as internal resorption and EARR. The latter is defined as any reduction in the radiographic lengths of the maxillary and mandibular teeth from the tip of the incisal edge or the tip of the most prominent cuspid to the apex of the root. This can be assessed with numerous methods, such as radiography, computed tomography (CT) and the Malmgren root resorption scoring system.[38,39]

This review synthesizes the available evidence regarding EARR; its results will allow orthodontists to make proper clinical decisions in order to minimize the risk of EARR severity. Thus, the aim of this systematic review was to compare EARR due to different conditions: 1) orthodontic systems (self-ligating compared to conventional), 2) dental trauma and 3) dental vitality.

Methods

Protocol and registration

The protocol for this systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD42021270140). It was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[40] and the Cochrane Handbook for Systematic Reviews of Interventions.[41] The PRISMA flow diagrams summarize all of the steps in the selection of included studies and were developed using an online tool.[42]

Eligibility criteria and participant characteristics of the studies

The eligibility criteria for inclusion were defined considering the Participants, Intervention, Comparator, and Outcome (PICO) strategy. The types of studies included in the systematic review were randomized controlled tri-

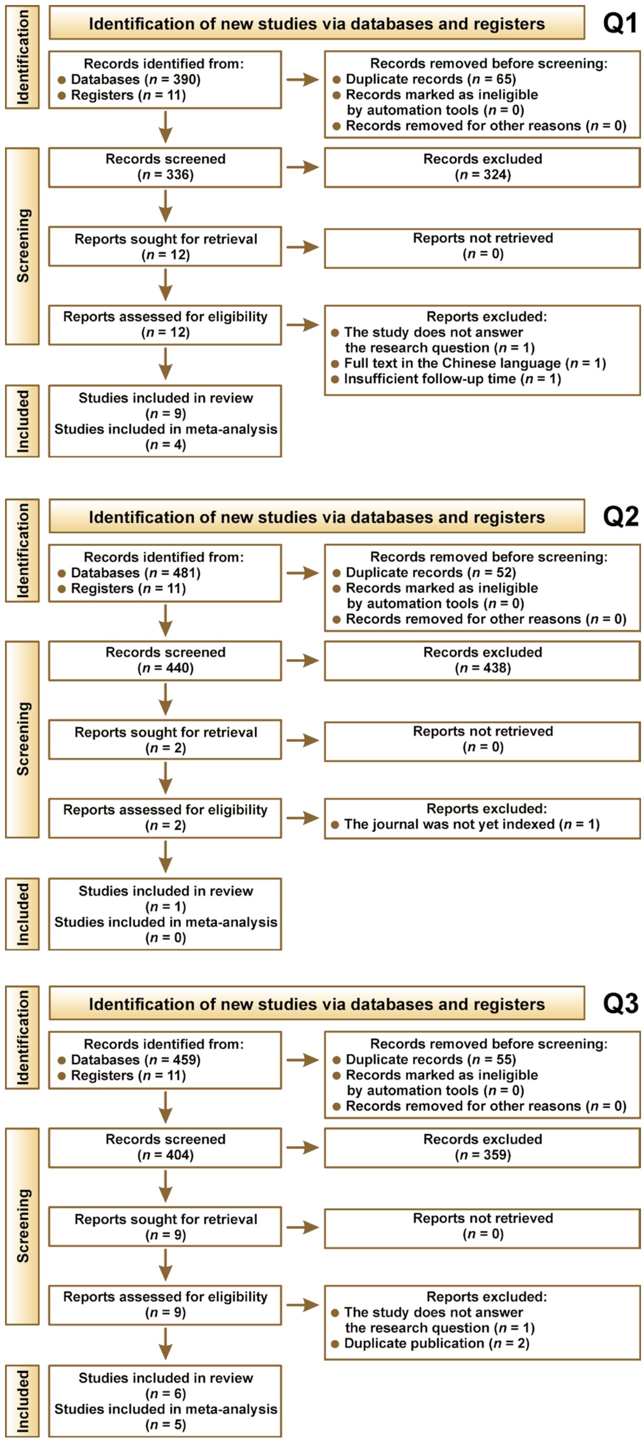


Fig. 1. PRISMA flow diagram search for studies of external apical root resorption (EARR) factors according to each research question

Table 1. Algorithms used in the search strategy adapted for each database and question

PICO strategy	Population: Patients with orthodontic treatment Interventions/condition: Q1 – self-ligating, Q2 – traumatized teeth, Q3 – non-vital teeth Comparator: Q1 – conventional brackets, Q2 – non-traumatized teeth, Q3 – vital teeth Outcomes: Root length, root resorption, root volume, Malmgren score
Focused questions	Q1 – What is the effect on the external apical root resorption induced by orthodontic treatment with self-ligating vs. conventional techniques? Q2 – What is the efffect of dental trauma on external apical root resorption in patients with orthodontic treatment? Q3 – What is the efffect on the external apical root resorption induced by orthodontic treatment in non-vital teeth vs. vital teeth?
Number of registers found for each database	Algorithms used in the search strategy adapted for each database and question
PubMed: Q1 = 7 Q2 = 2 Q3 = 4	Q1 = ("fixed appliances" OR "orthodontic treatment") AND (self-ligating AND (conventional OR "non-self-ligation" OR "traditional brackets")) AND ("apical root resorption" AND "external apical root resorption") Q2 = ("fixed appliances" OR "orthodontic treatment") AND ("traumatized teeth" OR "dental trauma") AND ("apical root resorption" AND "external apical root resorption") Q3 = ("fixed appliances" OR "orthodontic treatment") AND ("root canal treatment" OR "endodontic treatment" OR "non-vital teeth") AND ("apical root resorption" AND "external apical root resorption")
Google Scholar: Q1 = 334 Q2 = 439 Q3 = 395	Q1 = ("fixed appliances" OR "orthodontic treatment") AND ("self-ligating" AND ("conventional" OR "non-self-ligation" OR "traditional brackets")) AND ("apical root resorption" AND "external apical root resorption") Q2 = ("fixed appliances" OR "orthodontic treatment") AND ("traumatized teeth" OR "dental trauma") AND ("apical root resorption" AND "external apical root resorption") Q3 = ("fixed appliances" OR "orthodontic treatment") AND ("root canal treatment" OR "endodontic treatment" OR "non-vital teeth") AND ("apical root resorption" AND "external apical root resorption")
Clinical Trials: 11	orthodontic treatment | root resorption Applied filters: completed
ProQuest: Q1 = 7 Q2 = 2 Q3 = 4	Q1 = ("fixed appliances" OR "orthodontic treatment") AND (self-ligating AND (conventional OR "non-self-ligation" OR "traditional brackets")) AND ("apical root resorption" AND "external apical root resorption") Q2 = ("fixed appliances" OR "orthodontic treatment") AND ("traumatized teeth" OR "dental trauma") AND ("apical root resorption" AND "external apical root resorption") Q3 = ("fixed appliances" OR "orthodontic treatment") AND ("root canal treatment" OR "endodontic treatment" OR "non-vital teeth") AND ("apical root resorption" AND "external apical root resorption")
Web of Science: Q1 = 6 Q2 = 2 Q3 = 4	Q1: TS3 = ("fixed appliances" OR "orthodontic treatment") TS2 = (self-ligating AND (conventional OR "non-self-ligation" OR "traditional brackets")) TS1 = ("apical root resorption" AND "external apical root resorption") Q2: TS = ("fixed appliances" OR "orthodontic treatment") TS = ("traumatized teeth" OR "dental trauma") TS = ("apical root resorption" AND "external apical root resorption") Q3: TS = ("fixed appliances" OR "orthodontic treatment") TS = ("root canal treatment" OR "endodontic treatment" OR "non-vital teeth") TS = ("apical root resorption' AND "external apical root resorption")

als, nonrandomized clinical trials and observational studies. Case reports, case series, letters, comments, short communications, pilot studies (10 patients or less), animal studies, in vitro studies, in silico studies, and literature reviews were excluded. The eligible studies were full-text articles in English, Spanish or Portuguese. There were no publication date restrictions.

Information sources and search strategy

The search was performed on the electronic databases PubMed, ProQuest and Web of Science. The Google Scholar database was used to identify registers and protocols at ClinicalTrials.gov. The manual search was performed through bibliographical references of the studies included in the review (Fig. 1 and Table 1). This search was carried out from July 2019 to October 2019 and updated on June 15, 2021. The keywords and algorithms used for the search strategy are shown in Table 1. Two reviewers (HVS and RTR) performed the search and selection process. In the case of any disagreement, a 3rd reviewer (LAF) resolved the conflict.

Selection process

The studies were evaluated for inclusion in this systematic review by reading the title and abstract of each record identified by the search. The full text of each selected article that matched the eligibility criteria was retrieved for detailed analysis. If the full text did not fully meet the eligibility criteria, those studies were excluded with reasons.

Data collection process and data items

Microsoft Excel 2016 (Microsoft Corp., Redmond, USA) was used to generate spreadsheets to record the relevant data of the included studies. These included the demographic characteristics of the participants, groups studies, methodology used, results, baseline measures, follow-up measures, and *p*-values. Two reviewers were responsible for the data extraction (HVS and RTR). In addition, the corresponding authors of some included studies were contacted by email to obtain missing data or additional details.

Risk of bias in individual studies and quality assessment

Two reviewers (HVS and RTR) assessed the risk of bias of the included studies using the Risk of Bias in Non-Randomized Studies of Interventions (Robins-I) tool.[43] Next, the 2 reviewers (HVS and RTR) assessed the quality of the included studies using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach.[44] When there was a disagreement, a 3rd reviewer (LAF) resolved the differences of opinion.

Effect measures and synthesis methods

The main outcome of interest in this review was a decrease in root length related to orthodontic treatment. The effect measure of interest was the mean difference (*MD*) calculated for each study. Qualitative and quantitative syntheses were performed from the data of the included articles. The studies were grouped according to the outcomes that answered the review questions. For the meta-analysis, the information collected from the selected studies was carefully analyzed to determine whether the studies could be pooled. The standardized *MD*s were calculated from the individual studies and combined using a random-effects model. A 95% confidence interval (95% *CI*) and two-sided values were calculated. The heterogeneity between the studies in terms of measures of effect was evaluated using the heterogeneity statistic (I^2), considering that an I^2 value greater than 70% indicated substantial heterogeneity.

Results

Study selection and the results of individual studies

This section was divided according to the answers to Q1, Q2 and Q3. Regarding the archwire sequences used across the studies, the information was provided for some of the studies. Spurrier et al.,[45] Brin et al.,[46] Blake et al.,[47] Mirabella and Årtun,[36] Kreia et al.,[48] Esteves et al.,[49] Llamas-Carreras et al.,[50] Kawashima-Ichinomiya et al.,[51] and Castro et al.[52] did not provide such data. Pandis et al.[53] reported that the conventional group included 0.016 in and 0.020 in copper-nickel-titanium and finished with 0.019 in × 0.025 in stainless steel. In the self-ligating group, the archwire sequence involved a 0.014 in, a 0.016 in × 0.025 in copper-nickel-titanium, and a 0.019 in × 0.025 in stainless steel for finishing. Leite et al. only described that in both groups, the treatments used the same sequence of 0.013 in, 0.014 in, and 0.016 in nickel-titanium archwires; each kind of archwire remained for 2 months.[54] Jacobs et al. used an archwire sequence of a 0.015 in twistflex (stainless steel), 0.016 in nickel-titanium, 0.016 in × 0.022 in nickel-titanium, 0.017 in × 0.025 in nickel-titanium, and 0.019 in × 0.025 in stainless steel in all patients.[55] Chen et al.[39] utilized an initial 0.012 in or 0.014 in nickel-titanium, followed by 0.016 in, 0.018 in, 0.019 in × 0.025 in nickel-titanium, and 0.019 in × 0.025 in stainless steel archwires. For the self-ligating group, Aras et al. used an archwire sequence of 0.014 in copper-nickel-titanium, 0.016 in × 0.025 in copper-nickel-titanium, and 0.019 in × 0.025 in stainless steel, while the control group used 0.016 in copper-nickel-titanium (35°), 0.016 in × 0.022 in copper-nickel-titanium (35°), and 0.019 in × 0.025 in stainless steel archwires.[56] Qin and Zhou followed an archwire sequence that consisted of 0.012 in, 0.016 in, and 0.019 in × 0.025 in copper-nickel-titanium and finished with 0.019 in × 0.025 in stainless steel in the conventional group.[57] The archwire sequence for the self-ligating group included 0.014 in, 0.014 in × 0.025 in copper-nickel-titanium, and finished with 0.019 in × 0.025 in stainless steel.

Q1. EARR associated with orthodontic systems

A total of 390 records of articles were identified in the databases. Sixty-five duplicate records were removed, so 336 records remained, and their titles and abstracts were screened. Twelve articles were retrieved in full text; of these, 3 articles were removed, leaving 9 studies that met all eligibility criteria. The screening process is detailed in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Fig. 1), and the synthesis of the results is presented in Table 2.

Except for 2 studies, evaluations of the treatments were carried out at the beginning of the orthodontic treatment and after treatment.[39,47,51,53,55,57,58] Leite et al. measured EARR before and 6 months after orthodontic treatment initiation.[54] Aras et al. evaluated EARR before and 9 months after the treatment started.[56]

Blake et al. found no statistically significant difference in EARR between self-ligating and conventional appliances.[47] In particular, gender and duration of treatment were not indicators related to EARR. Pandis et al. reported no significant difference between the appliances used.[53] In particular, age, gender, duration of treatment, and dental extractions were not variables related to EARR. Leite et al. found no differences in EARR between the groups studied on the maxillary and mandibular incisors.[54] Kawashima-Ichinomiya et al. reported a statistically significant difference in EARR in favor of self-ligating appliances.[51] In addition, IL-6 levels were evaluated, which were lower in patients treated with self-ligating brackets than in those with conventional brackets.[51] Jacobs et al. reported that there was no difference in EARR between the appliances used.[55] However, using the Malmgren score, they found that the right maxillary central incisors and left maxillary lateral incisors had less EARR (grade 1), while the mandibular central incisors exhibited more EARR (grade 4). Chen et al. also reported no statistically significant differences in EARR using different appliances.[39] Likewise, that study evaluated EARR according to the Malmgren system and found that the self-ligating system group showed a greater distribution of frequencies in grades 1 and 2 compared to conventional appliances. However, the authors did not perform a statistical analysis to determine if there were differences between the grades according to the Malmgren score. Handem et al. found no statistically significant difference between self-ligating and conventional brackets.[58] Aras et al. reported that there were no statistically significant differences in root volume loss between the self-ligating and conventional systems.[56] Qin and Zhou evaluated EARR in patients with class I malocclusion and dental extractions.[57] They found no statistically significant differences in the amount of EARR between the brackets used. Age and gender were not associated with EARR; however, EARR was positively correlated with duration of treatment.

Table 2. Characteristics and results of the included studies of the EARR associated with orthodontic treatment

	Reference	Patients	Groups	Age [years]	Teeth	Assessment method	Results
Q1. Self-ligating vs. conventional techniques	Blake et al. 1995	$n = 63$	GI: conventional fixed appliances, slot 0.018 (Edgewise) ($n = 33$) GII: self-ligating fixed appliances, slot 0.018 (no data) ($n = 30$)	$M \pm SD$ GI: 13 ±2.7 GII:12.10 ±2.3	maxillary lateral incisors maxillary central incisors mandibular lateral incisors mandibular central incisors	panoramic radiograph	EARR $M \pm SD$ maxillary central incisors: GI: 9.41 ±8.63; GII: 7.29 ±6.44 mandibular lateral incisors: GI: 12.83 ±8.65; GII: 12.21 ±9.25 mandibular central incisors: GI: 4.60 ±7.94; GII: 7.36 ±6.86 mandibular lateral incisors: GI: 7.27 ±7.91; GII: 5.00 ±7.63 ($p > 0.05$)
	Pandis et al. 2008	$n = 96$	GI: conventional fixed appliances, slot 0.022 (Microarch) ($n = 48$) GII: self-ligating fixed appliances slot 0.022 (Damon 2) ($n = 48$)	$M \pm SD$ 13.21 ±1.64	maxillary incisors mandibular incisors	panoramic radiograph	EARR $M \pm SD$ maxillary incisors:1.23 ±0.97 mandibular incisors:1.36 ±0.90 univariate model: ($\beta = 0.40$, $SE = 0.26$, p = NS) multivariate model: ($\beta = 0.37$, $SE = 0.20$, $p = 0.06$) ($p > 0.05$)
	Leite et al. 2012	$n = 19$	GI: passive self-ligating fixed appliances, slot 0.022 (Easyclip) ($n = 11$) GII: conventional pre-adjusted fixed appliances, slot 0.022 (3M Unitek) ($n = 8$)	M: 20.6 range: 11–30	maxillary central incisor maxillary lateral incisor mandibular central incisor mandibular lateral incisor	CBCT	EARR $M \pm SD$ maxillary central incisor: GI: −0.34 ±0.24; GII: −0.33 ±0.19 maxillary lateral incisor: GI: −0.43 ±0.33; GII: −0.44 ±0.33 mandibular central incisor: GI: −0.39 ±0.52; GII: −0.31 ±0.21 mandibular lateral incisor: GI: −0.23 ±0.23; GII: −0.40 ±0.24 ($p > 0.05$)
	Kawashima-Ichinomiya et al. 2012	$n = 60$	GI: passive self-ligating fixed appliances, slot no data (Damon) ($n = 30$) GII: conventional fixed appliances, slot 0.022 (Edgewise) ($n = 30$)	$M \pm SD$ 18 ±5.3	maxillary central incisor	periapical radiographs and cephalograms	EARR $M \pm SD$ maxillary central incisor: GI 2.5 ±1.5; GII: 0.88 ±0.9 ($p = 0.005$)
	Jacobs et al. 2014	$n = 213$	GI: self-ligating fixed appliances, slot 0.022 (Smart clip) ($n = 139$) GII: conventional fixed appliances, slot 0.022 (Victory) ($n = 74$)	$M \pm SD$ 12.4 ±2.2	maxillary and mandibular incisors	panoramic radiograph	rRR $M \pm SD$ GI: 3.0 ±5.6; GII: 4.5 ±6.6 sEARR % GI: n = 3–0.3%; GII: n = 3–0.5% ($p = 0.33$)

	Reference	Patients	Groups	Age [years]	Teeth	Assessment method	Results
Q1. Self-ligating vs. conventional techniques	Chen et al. 2015	*n* = 70	GI: passive self-ligating fixed appliances, slot 0.022 (Damon 3) (*n* = 35) GII: conventional fixed appliances, slot 0.022 (3M Unitek) (*n* = 35)	*M* ±*SD* GI:13.52 ±2.84 GII:13.42 ±2.50	maxillary central incisor maxillary lateral incisor mandibular central incisor mandibular lateral incisor	periapical radiograph	EARR *M* ±*SD* maxillary central incisor: GI: 0.3 ±0.4; GII: 0.5 ±0.3 maxillary lateral incisor: GI: 0.2 ±0.3; GII: 0.3 ±0.5 mandibular central incisor: GI: 0.4 ±0.4; GII: 0.4 ±0.5 mandibular lateral incisor: GI: 0.3 ±0.3; GII: 0.3 ±0.5 ($p > 0.05$) Malmgren score: GI: *n* = 280 (%) score 0: 0 (0%) score 1: 188 (67.14%) score 2: 67 (23.93%) score 3: 22 (7.86%) score 4: 3 (1.07%) GII: *n* = 280 (%) score 0: 0 (0%) score 1: 156 (55.71%) score 2: 70 (25.00%) score 3: 48 (17.14%) score 4: 6 (2.14%) teeth *n* = 560 (%) score 0: 0 (0%) score 1: 344 (61.4%) score 2: 137 (24.4%) score 3: 70 (12.5%) score 4: 9 (1.6%) (*p* = ND)
	Handem et al. 2016	*n* = 52	GI: self-ligating fixed appliances, slot 0.022 (Damon) (*n* = 25) GII: conventional fixed appliances, slot 0.022 (Roth) (*n* = 27)	range: GI:16.04–18.06 GII:16.77–18.47	maxillary central incisor maxillary lateral incisor mandibular central incisor mandibular lateral incisor	periapical radiograph	EARR M [±*SD*?] maxillary right central incisor: GI: 0.72; GII: 0.59 maxillary right lateral incisor: GI: 0.72; GII: 0.70 maxillary left central incisor: GI: 0.88; GII: 0.66 maxillary left lateral incisor: GI: 0.80; GII: 0.74 mandibular right central incisor: GI: 0.64; GII: 0.66 mandibular right lateral incisor: GI: 0.48; GII: 0.40 mandibular left central incisor: GI: 0.60; GII: 0.62 mandibular left lateral incisor: GI: 0.56; GII: 0.55 ($p > 0.05$) Malmgren score: GI: *n* = 200 (%) score 0: 93 (46.5%) score 1: 83 (41.5%) score 2: 20 (10%) score 3: 4 (2%) score 4: 0 (0%) GII: *n* = 216 (%) score 0: 114 (52.7%) score 1: 74 (34.2%) score 2: 24 (11.1%) score 3: 4 (1.85%) score 4: 0 (0%) teeth *n* = 560 (%) score 0: 207 (49.7%) score 1: 157 (37.7%) score 2: 44 (10.5%) score 3: 8 (1.92%) score 4: 0 (0%) (*p* = ND)

	Reference	Patients	Groups	Age [years]	Teeth	Assessment method	Results
Q1. Self-ligating vs. conventional techniques	Aras et al. 2018	*n* = 32	GI: self-ligating fixed appliances, slot 0.022 (Damon Q) (*n* = 16) GII: conventional fixed appliances, slot 0.022 (Titanium Orthos) (*n* = 16)	*M* ±*SD*: GI:15.00 ±1.03 GII:14.94 ±1.06	central incisor lateral incisor	CBCT	volumetric changes *M* ±*SD* central incisor: GI: 27.08 ±12.71; GII: 28.29 ±13.48 intergroup differences: ($p = 0.712$) lateral incisor: GI: 20.32 ±11.67; GII: 19.77 ±11.05 intergroup differences: ($p = 0.587$)
	Qin and Zhou 2019	*n* = 98	GI: self-ligating fixed appliances, slot 0.019 (Damon 3) (*n* = 49) GII: conventional fixed appliances, slot 0.019 (3M Unitek) (*n* = 49)	*M* ±*SD*: GI: 15.21 ±4.43 GII:15.15 ±4.52	maxillary central incisor maxillary lateral incisor mandibular central incisor mandibular lateral incisor	panoramic radiograph	EARR *M* ±*SD* maxillary right central incisor: GI: –0.32 ±0.24; GII: –0.40 ±0.28 maxillary right lateral incisor: GI: –0.27 ±0.28; GII: –0.30 ±0.25 maxillary left central incisor: GI: –0.33 ±0.27; GII: –0.39 ±0.31 maxillary left lateral incisor: GI: –0.28 ±0.25; GII: –0.31 ±0.26 ($p > 0.05$)
Q2. Dental trauma vs. non-dental trauma	Brin et al. 1991	*n* = 139	group T: 'trauma' group (*n* = 56) group O: 'orthodontic' group (*n* = 29) group TO: 'trauma-orthodontic' group (*n* = 28) group C: 'intact' control group (*n* = 26)	M: 13.7	maxillary incisors	periapical radiograph	prevalence of root resorption (%): group T: 7.8% group O: 6.7% group TO: 27.8% group C: 0.0%
Q3. Non-vital vs. vital teeth	Spurrier et al. 1990	*n* = 43	split-mouth GI: RFT GII: VHT	range: 13–11	incisors	periapical radiographs	EARR *M* ±*SD* RFT: 1.28 ±1.09 VHT: 2.05 ±1.49 ($p = 0.006$)
	Mirabella and Årtun 1995	*n* = 36	split-mouth GI: RFT GII: VHT	range: 20–70	anterior maxillary teeth	periapical radiographs and cephalograms	The mean difference in root resorption between the contralateral pairs of teeth (*n* = 39) with and without endodontic treatment was 0.45 ±1.21 ($p < 0.05$).
	Kreia et al. 2005	*n* = 40	split-mouth GI: RFT GII: VHT	ND	maxillary incisors	periapical radiographs	EARR *M* ±*SD* RFT: 1.14 ±1.03 VHT: 1.34 ±1.35 ($p = 0.903$)
	Esteves et al. 2007	*n* = 16	split-mouth GI: RFT GII: VHT	ND	maxillary incisors	periapical radiographs	EARR *M* ±*SD* RFT: 0.82 ±1.19 VHT: 1.04 ±1 ($p = 0.29$)
	Llamas-Carreras et al. 2012	*n* = 38	split-mouth GI: RFT GII: VHT	*M* ±*SD* 31 ±10	maxillary incisors	digital panoramic radiographs	EARR *M* ±*SD* RFT: 1.1 ±0.8 VHT: 1.1 ±1.0 PRR: 1.0 ±0.2 ($p > 0.05$)
	Castro et al. 2015	*n* = 20	split-mouth GI: RFT GII: VHT	range: 11–15	posterior teeth	CBCT	tooth length *M* ±*SD* RFT before orthodontic treatment: 20.55 ±1.21 after orthodontic treatment: 20.25 ±1.18 VHT before orthodontic treatment: 20.29 ±1.33 after orthodontic treatment: 20.13 ±1.57 ($p = 0.4197$)

GI – group I; GII – group II; rRR – relative root resorption; EARR – external apical root resorption; sEARR – severe external apical root resorption; *M* – mean; *M* ±*SD* – mean ± standard deviation; 95% *CI* – 95% confidence interval; *OR* – odds ratio; *SE* – standard error; ND – no data; NS – not statistically significant; CBCT – cone-beam computed tomography; RFT – root filled tooth; VHT – vital homologous teeth; PRR – proportion of root resorption.

Risk of bias and quality assessment

The studies included in this review showed moderate risk of bias. The main deficiencies were found in the domains Confounding (100%), Missing data (55%), Deviations from interventions (11%), and Measuring outcomes (11%). The quality of the articles was low to moderate, with a critical level of evidence. Risk of bias and the results of quality assessments are shown in Fig.2 and Tables 3–5, respectively.

Meta-analysis

The heterogeneity found in the meta-analysis of EARR of maxillary central incisor teeth was very high (I^2 = 89%). No statistically significant difference was found between the EARR of teeth orthodontically treated with self-ligating and conventional techniques (p = 0.76). When analyzing the variations between the results of the studies, it was found that there were differences in both the age and sex of the participants that could have influenced the effect of the intervention. The age of the participants varied considerably. In 2 of the studies,[51,54] the mean age was 18.0 ±5.3 years and 20.6 years, while in the other 2 studies,[39,57] the mean age was 13.52 ±2.84 years and 15 years. Thus, it is apparent that the participants in the first 2 studies were young adults, while the last 2 studies evaluated adolescent participants. Additionally, the female:male ratio in 1 study was 3:1,[51] while it was 1:1 in the other

Table 3. Quality assessment of the included studies that evaluated EARR associated with orthodontic treatment (Q1. Self-ligating vs. conventional appliances)

	Certainty assessment						Number of patients		Effect		Certainty	Importance
	Number of studies	study design	risk of bias	inconsistency	indirectness	imprecision	NO-SL	SL	relative (95% CI)	absolute (95% CI)		
Maxillary central incisors	4	observational studies	serious	serious	not serious	not serious	106	106	–	MD 0.3 lower (0.86 lower to 0.26 higher)	⊕⊕OO low	critical
Maxillary lateral incisors	3	observational studies	serious	not serious	not serious	not serious	76	76	–	MD 0.07 higher (0.09 lower to 0.24 higher)	⊕⊕⊕O moderate	critical
Mandibular central incisors	3	observational studies	serious	not serious	not serious	not serious	76	76	–	MD 0.04 lower (0.25 lower to 0.18 higher)	⊕⊕⊕O moderate	critical
Mandibular lateral incisors	3	observational studies	serious	not serious	not serious	not serious	76	76	–	MD 0.08 higher (0.1 lower to 0.27 higher)	⊕⊕⊕O moderate	critical

95% *CI* – 95% confidence interval; *MD* – mean difference.

Table 4. Quality assessment of the included studies that evaluated EARR associated with orthodontic treatment (Q2. Dental trauma vs. non-dental trauma)

Number of studies	Results	Impact	Number of participants	Certainty	Importance
1	Reabsorption from dental trauma. Evaluated using periapical radiographs. Follow-up: Half a year after the end of the retention period.	Reabsorption was more frequent indirectly injured teeth than in the group with dental trauma before orthodontic treatment. No further information.	139	⊕OOO very low	critical

95% *CI* – 95% confidence interval; *MD* – mean difference.

Table 5. Quality assessment of the included studies that evaluated EARR associated with orthodontic treatment (Q1. Self-ligating vs. conventional appliances)

	Certainty assessment						Number of patients		Effect		Certainty	Importance
	Number of studies	study design	risk of bias	inconsistency	indirectness	imprecision	Endodontically treated	Vital teeth	relative % (95% CI)	absolute % (95% CI)		
Non-vital vs. vital incisor teeth	5	observational studies	serious	serious	not serious	not serious	145	145	–	MD 0.28 lower (0.51 lower to 0.05 lower)	⊕⊕OO low	critical
Non-vital vs. vital posterior teeth	1	observational studies	serious	serious	not serious	not serious	20	20	–	MD 0.2 higher (0.42 lower to 0.82 higher)	⊕⊕⊕O moderate	critical

95% *CI* – 95% confidence interval; *MD* – mean difference.

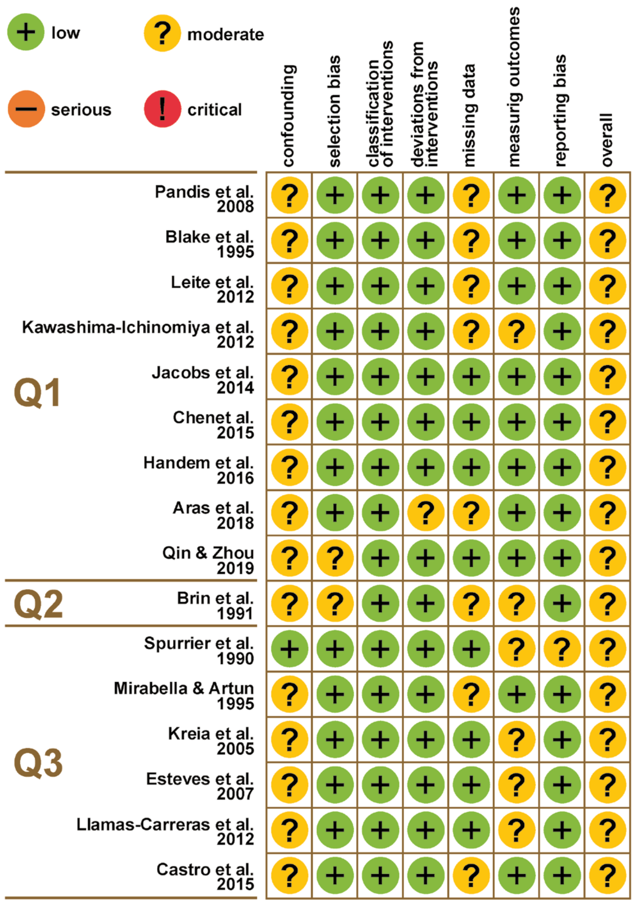


Fig. 2. Risk of bias in the included studies that assessed EARR factors according to each research question

3 studies.[39,54,57] Although the 4 studies included in this meta-analysis exhibited moderate risk of bias, 1 presented more domains with risk of bias[51] compared to the other studies (Fig. 3). In the meta-analysis of the EARR of the maxillary lateral incisor teeth, there was no statistically significant difference (Fig. 3). In the meta-analysis of the EARR of the mandibular central incisor teeth, there was no statistically significant difference between the appliances (Fig. 3). There was no heterogeneity in either analysis. In the meta-analysis of the EARR of the mandibular lateral incisor teeth, it was found that there was no statistically significant difference (p = 0.49); moderate heterogeneity was demonstrated (Fig. 3).

Q2. EARR associated with dental trauma

The search identified a total of 481 articles. Fifty-two duplicate records were removed, so the titles and abstracts of 440 records that remained were screened. Two articles were retrieved in full text; 1 article was removed,[38] resulting in 1 study that met all of the eligibility criteria. The screening process is detailed in the PRISMA flow diagram (Fig. 1), and the synthesis of the results is presented in Table 2.

Brin et al. evaluated the EARR of traumatized permanent maxillary incisors which underwent orthodontic treatment using periapical radiographs, with a 6-month follow-up after completion of the retention period.[46] That study examined 4 groups: with dental trauma, with orthodontic treatment, with trauma and orthodontic treatment, and the control group without trauma or orthodontic treatment. The results suggest that the combination of dental trauma and orthodontic treatment results in teeth that are more susceptible to RR. This study evaluated EARR linked to treatment duration without finding any correlation.

Risk of bias and quality assessment

The included study showed moderate risk of bias; the main deficiencies were found in the Confounding, Selection bias, Missing data, and Measuring outcome domains. In the quality assessment, very low certainty of the evidence was observed due to 1) risk of bias, 2) non-assessable consistency between findings in the literature for a single study on the effect of trauma on EARR during orthodontic treatment, and 3) indirection due to the evaluation of a surrogate variable. Risk of bias and quality assessments are shown in Fig. 2 and Tables 3–5, respectively.

Q3. EARR associated with dental vitality

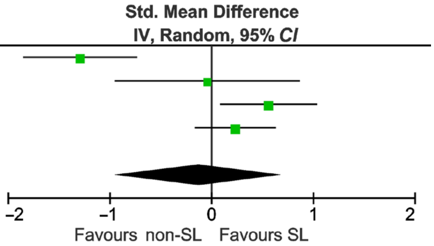
The search identified a total of 459 records of articles. Fifty-five duplicate records were removed, so 404 records remained, and their titles and abstracts were screened. Nine articles were retrieved in full text; of these, 3 articles were removed,[59–61] resulting in 6 studies[36,45,48–50,52] that met all of the eligibility criteria; there were 173 participants in total. Mirabella and Årtun[36,59] reported the results from 2 articles, and Llamas-Carreras et al.[50,60] reported results from 2 articles as well. Thus, this review included only 1 study by Mirabella and Årtun[36] and 1 study by Llamas-Carreras et al.[50] which provided the necessary data for answering the review question. The screening process is detailed in the PRISMA flow diagram (Fig. 1), and the synthesis of the results is shown in Table 2.

The measurements to determine the amount of EARR in all of the studies were performed before and after orthodontic treatment and had a split-mouth design. Corresponding vital homologous teeth were used as controls for comparison. Spurrier et al.[45] demonstrated that vital homologous teeth suffered more resorption than endodontically treated teeth; this difference was statistically significant. This study assessed EARR linked to gender and found no correlation. Mirabella and Årtun,[36] Kreia et al.,[48] Esteves et al.,[49] Llamas-Carreras et al.,[50] and Castro et al.[52] reported that non-vital teeth exhibited similar resorption to their contralateral vital teeth.

Q1. Maxillary central incisors

Study or Subgroup	non-SL *M*	non-SL *SD*	non-SL Total	SL *M*	SL *SD*	SL Total	Weight	Std. Mean Difference IV, Random, 95% *CI*	Year
Kawashima-Ichinomiya et al.	0.88	0.9	30	2.5	1.5	30	25.4%	−1.29 (−1.85, −0.73)	2012
Leite et al.	0.33	0.19	8	0.34	0.24	11	21.3%	−0.04 (−0.95, 0.87)	2012
Chen et al.	0.5	0.3	35	0.3	0.4	35	26.3%	0.56 (0.08, 1.04)	2015
Qin and Zhou	0.39	0.34	49	0.32	0.25	49	27.0%	0.23 (−0.16, 0.63)	2019
Total (95% *CI*)			**122**			**125**	**100.0%**	**−0.13 (−0.94, 0.69)**	

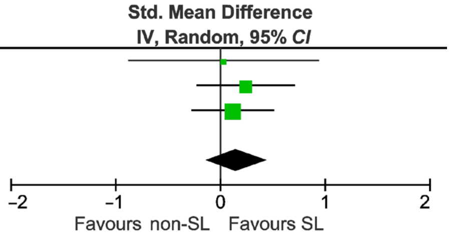
Heterogeneity: $\tau^2 = 0.60$; $\chi^2 = 27.05$, df = 3 ($p < 0.00001$); $I^2 = 89\%$
Test for overall effect: $Z = 0.31$ ($p = 0.76$)



Q1. Maxillary lateral incisors

Study or Subgroup	non-SL *M*	non-SL *SD*	non-SL Total	SL *M*	SL *SD*	SL Total	Weight	Std. Mean Difference IV, Random, 95% *CI*	Year
Leite et al.	0.44	0.33	8	0.43	0.33	11	10.0%	0.03 (−0.88, 0.94)	2012
Chen et al.	0.3	0.5	35	0.2	0.3	35	37.4%	0.24 (−0.23, 0.71)	2015
Qin and Zhou	0.3	0.25	49	0.27	0.26	49	52.6%	0.12 (−0.28, 0.51)	2019
Total (95% *CI*)			**92**			**95**	**100.0%**	**0.15 (−0.13, 0.44)**	

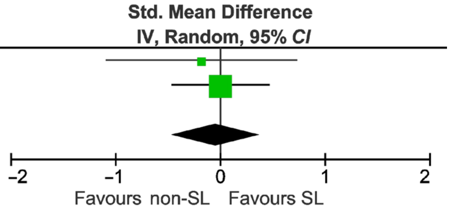
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.23$, df = 2 ($p = 0.89$); $I^2 = 0\%$
Test for overall effect: $Z = 1.05$ ($p = 0.29$)



Q1. Mandibular central incisors

Study or Subgroup	non-SL *M*	non-SL *SD*	non-SL Total	SL *M*	SL *SD*	SL Total	Weight	Std. Mean Difference IV, Random, 95% *CI*	Year
Leite et al.	0.31	0.21	8	0.39	0.52	11	20.8%	−0.18 (−1.09, 0.73)	2012
Chen et al.	0.4	0.5	35	0.4	0.4	35	79.2%	0.00 (−0.47, 0.47)	2015
Total (95% *CI*)			**43**			**46**	**100.0%**	**−0.04 (−0.45, 0.38)**	

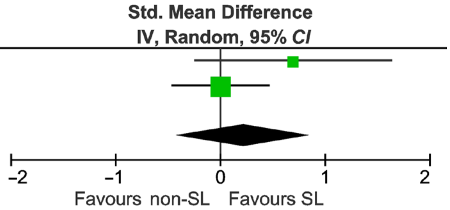
Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.12$, df = 1 ($p = 0.73$); $I^2 = 0\%$
Test for overall effect: $Z = 0.18$ ($p = 0.86$)



Q1. Mandibular lateral incisors

Study or Subgroup	non-SL *M*	non-SL *SD*	non-SL Total	SL *M*	SL *SD*	SL Total	Weight	Std. Mean Difference IV, Random, 95% *CI*	Year
Leite et al.	0.4	0.24	8	0.23	0.23	11	31.8%	0.69 (−0.25, 1.64)	2012
Chen et al.	0.3	0.5	35	0.3	0.3	35	68.2%	0.00 (−0.47, 0.47)	2015
Total (95% *CI*)			**43**			**46**	**100.0%**	**0.22 (−0.41, 0.85)**	

Heterogeneity: $\tau^2 = 0.10$; $\chi^2 = 1.66$, df = 1 ($p = 0.20$); $I^2 = 40\%$
Test for overall effect: $Z = 0.68$ ($p = 0.49$)



Q3. Anterior teeth

Study or Subgroup	non-vital Teeth *M*	non-vital Teeth *SD*	non-vital Teeth Total	Vital teeth *M*	Vital teeth *SD*	Vital teeth Total	Weight	Std. Mean Difference IV, Random, 95% *CI*	Year
Spurrier et al.	1.28	1.09	43	2.05	1.49	43	28.9%	−0.58 (−1.02, −0.15)	1990
Mirabella and Årtun	0.91	1.03	28	1.38	1.53	28	19.3%	−0.36 (−0.88, 0.17)	1995a
Kreia et al.	1.14	1.03	20	1.34	1.35	20	14.0%	−0.16 (−0.78, 0.46)	2005
Esteves et al.	0.82	1.19	16	1.04	1	16	11.2%	−0.20 (−0.89, 0.50)	2007
Llamas-Carreras et al.	1.1	0.8	38	1.1	1	38	26.7%	0.00 (−0.45, 0.45)	2012
Total (95% *CI*)			**145**			**145**	**100.0%**	**−0.28 (−0.51, −0.05)**	

Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 3.67$, df = 4 ($p = 0.45$); $I^2 = 0\%$
Test for overall effect: $Z = 2.38$ ($p = 0.02$)

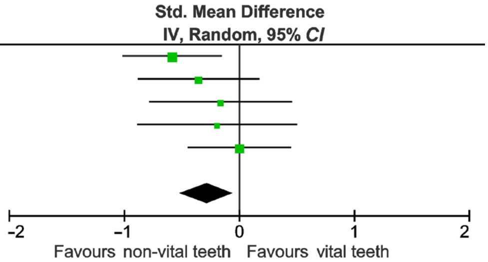


Fig. 3. Forrest plots of EARR on anterior teeth using self-ligation (SL) compare to conventional (Non-SL) appliances and non-vital compared to vital teeth

Risk of bias and quality assessment

The included studies showed moderate risk of bias; the main deficiencies were found in the Confounding (85.7%), Missing data (42.8%), Measuring outcomes (42.8%), and Reporting bias (14%) domains. The quality of the studies was low, with a critical level of evidence. The risk of bias and quality assessments are shown in Fig. 2 and Tables 3–5, respectively.

Meta-analysis

The sample analyzed by Mirabella and Årtun[36] consisted of 36 patients with 39 endodontically treated and their vital homologous anterior teeth, which included the canines. However, for the meta-analysis, the remaining studies used the incisors only. As a result, a subgroup from the sample was used following the same strategy as previously reported in a systematic review by Ioannidou-Marathiotou et al.[62] The study that evaluated the amount of EARR in molar teeth was not included in the meta-analysis due to the type of teeth studied.[52] The data from 145 patients was pooled in the meta-analysis of EARR for non-vital and vital teeth.[36,45,48–50] It was determined that there was a statistically significant difference between the groups; i.e., the non-vital teeth showed less EARR compared to their contralateral vital teeth following orthodontic treatment (Fig. 3).

Discussion

Q1. EARR produced by the self-ligating compared to conventional techniques

Analysis of the articles included in this systematic review suggested that there is no statistically significant difference in EARR when comparing self-ligating and conventional techniques. However, 9 observational articles were analyzed that had moderate risk of bias and moderate quality of evidence. No controlled clinical trials were found; therefore, the studies provide limited evidence.

A review performed by Yi et al. evaluated studies of EARR due to orthodontic treatment with self-ligating and conventional techniques.[63] They assessed 7 studies, 5 of which were pooled for a meta-analysis.[39,47,54,64,65] Their results suggest that the use of self-ligating brackets causes less EARR in maxillary central incisor teeth during orthodontic treatment (without differences in the rest of the teeth evaluated). However, the studies included in that review had moderate risk of bias, and no quality assessment was performed. Their heterogeneity results (I^2 = 0) did not correlate with the confidence intervals and direction of effect from the included studies. Finally, concerning the maxillary lateral incisors, mandibular central incisors and mandibular lateral incisors, there was no statistically significant difference in the amount of EARR between the 2 techniques.

Q2. EARR of traumatized compared to non-traumatized teeth

Resorption was more frequent in directly injured teeth in the group with dental trauma before orthodontic treatment; however, the study by Brin et al. was observational and had moderate risk of bias and very low quality.[46] No controlled clinical trials were found. Consequently, the evidence is limited, so more studies are required to determine whether there is a direct relationship between previous dental trauma and EARR in patients undergoing orthodontic treatment. In the same sense, no systematic reviews of this topic were found.

Q3. EARR of non-vital compared to vital teeth

The included studies suggest that there is a statistically significant difference in the amount of EARR in endodontically treated teeth compared to homologous vital teeth after orthodontic treatment. In this systematic review, 6 observational studies were analyzed; 5 of those included in the meta-analysis showed low quality.[36,45,48–50] When conducting the bias assessment, these studies were determined to have moderate risk of bias. No controlled clinical trials were found. Consequently, the evidence is limited regarding the effect of orthodontic treatment on the amount of EARR in non-vital compared to vital teeth.

The systematic review carried out by Ioannidou-Marathiotou et al.[62] assessed 6 studies[36,45,48,49,59,60] that focused on the amount of EARR in endodontically treated teeth after orthodontic treatment. The authors of the review reported that endodontically treated teeth exhibited relatively less RR than teeth with vital pulps. Their meta-analysis included 4 articles[36,45,48,49] and revealed a statistically significant difference (p = 0.005) between the groups and low heterogeneity (I^2 = 0%) across the studies. In the review by this research team, no evaluation of bias was performed. In addition, the overall quality of the included studies was considered low.

Currently, there are no specific and effective treatments for EARR. Nanotechnology has been used as a novel approach for dentistry treatments[66–69]; in that sense, chitosan and hydroxyapatite nanoparticles have been developed for the treatment of EARR. Unfortunately, the studies that have been carried out so far have been animal models and case reports.[70,71] Consequently, the only proven available management of EARR is preventive through adequate diagnosis and orthodontic treatment.

On the current market, clear aligner therapy (CAT) has become a popular option when compared to fixed appliances due to its advantages of superior esthetics and comfort.[72] Aldeeri et al. performed a systematic review that aimed to evaluate the evidence concerning EARR in CAT during orthodontic treatment.[73] They reported a low risk of EARR associated with CAT. However, due to the design and quality of the included studies, solid evidence could not be established. Later, Fang et al. performed a meta-analysis aimed at assessing the amount of EARR in patients undergoing orthodontic treatment with CAT compared to those treated with fixed appliances.[74] They reported that the incidence and severity of EARR were lower in those using CAT. Finally, Gandhi et al. carried out a meta-analysis that aimed to investigate EARR in patients treated with pre-adjusted edgewise appliances compared to those treated with CAT.[75] They concluded that neither pre-adjusted edgewise appliances nor CAT resulted in clinically significant EARR. However, the amount of EARR was higher in the pre-adjusted edgewise appliance users only in tooth 12. We can conclude that the use of CAT could diminish the risk of EARR. However, there is a lack of satisfactory quality of evidence in the studies included in the previously mentioned reviews.

At present, the number of publications in basic science, observational studies and clinical trials has been increasing exponentially. However, randomized clinical trials are considered the best evidence to evaluate a health problem. The literature includes mixed reports of basic science results that are not automatically reflected in clinical practice.[76,77] Moreover, several publications in dentistry report divergent results despite presenting characteristics that superficially seem similar or use different variables to determine the effect of an intervention.[78,79] Hence the importance of evidence-based medicine aimed to determine the validity and analyze the data set of published studies through systematic reviews.

Limitations

This review encountered several limitations, including limited research in the field, moderate risk of bias, low quality of the observational studies, and lack of randomized clinical trials that met the inclusion criteria.

Conclusions

The evidence suggests that the EARR induced by orthodontic treatment with self-ligating or conventional brackets is similar, regardless of the technique used. However, although the meta-analysis had low heterogeneity, the included studies exhibited a moderate risk of bias and low to moderate quality. Future studies are required with adequate internal and external validity, and EARR assessment methods used in the future should be more accurate.

The evidence on the effect of dental trauma on EARR during orthodontic treatment is limited, with very low quality and moderate risk of bias in the studies assessed. There are no conclusive results from this analysis.

The current evidence suggests that the amount of EARR during orthodontic treatment in endodontically treated teeth is lower than in vital teeth. However, the included studies showed a moderate risk of bias and low quality.

Ethics approval and consent to participate

Not applicapble.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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