Root resorption associated with orthodontic tooth movement: A systematic review

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Introduction: This systematic review evaluated root resorption as an outcome for patients who had orthodontic tooth movement. The results could provide the best available evidence for clinical decisions to minimize the risks and severity of root resorption. **Methods:** Electronic databases were searched, nonelectronic journals were hand searched, and experts in the field were consulted with no language restrictions. Study selection criteria included randomized clinical trials involving human subjects for orthodontic tooth movement, with fixed appliances, and root resorption recorded during or after treatment. Two authors independently reviewed and extracted data from the selected studies on a standardized form. **Results:** The searches retrieved 921 unique citations. Titles and abstracts identified 144 full articles from which 13 remained after the inclusion criteria were applied. Differences in the methodologic approaches and reporting results made quantitative statistical comparisons impossible. Evidence suggests that comprehensive orthodontic treatment causes increased incidence and severity of root resorption, and heavy forces might be particularly harmful. Orthodontically induced inflammatory root resorption is unaffected by archwire sequencing, bracket prescription, and self-ligation. Previous trauma and tooth morphology are unlikely causative factors. There is some evidence that a 2 to 3 month pause in treatment decreases total root resorption. **Conclusions:** The results were inconclusive in the clinical management of root resorption, but there is evidence to support the use of light forces, especially with incisor intrusion. (Am J Orthod Dentofacial Orthop 2010;137:462-76)

At present, it is unknown how orthodontic treatment factors influence root resorption (RR). The etiologic factors are complex and multifactorial, but it appears that apical RR results from a combination of individual biologic variability, genetic predisposition, and the effect of mechanical factors. RR is undesirable because it can affect the long-term viability of the dentition, and reports in the literature indicate that patients undergoing orthodontic treatment are more likely to have severe apical root shortening.[1,2] Patient factors such as genetics and external factors including trauma are also thought to be associated with increased RR.[3-5]

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Many general dentists and other dental specialists believe that RR is avoidable and hold the orthodontist responsible when it occurs during orthodontic treatment.[6] It is therefore important to identify which orthodontic treatment factors contribute to RR, so that the detrimental effects can be minimized and RR reduced.

Histologic studies reported greater than a 90% occurrence of orthodontically induced inflammatory RR (OIIRR) in orthodontically treated teeth.[7-9] Lower percentages were reported with diagnostic radiographic techniques. Lupi and Linge[10] reported the incidence of external apical RR (EARR) at 15% before treatment and 73% after treatment. In most cases, the loss of root structure was minimal and clinically insignificant.

With panoramic or periapical radiographs, OIIRR is usually less than 2.5 mm,[11-15] or varying from 6% to 13% for different teeth.[16] By using graded scales, OIIRR is usually classified as minor or moderate in most orthodontic patients.[17-20] Severe resorption, defined as exceeding 4 mm, or a third of the original root length, is seen in 1% to 5% of teeth.[10,17-19,21-23]

Regardless of genetic or treatment-related factors, the maxillary incisors consistently average more apical RR than any other teeth, followed by the mandibular incisors and first molars.[12,15,20,24-28]

Orthodontic treatment-related risk factors include treatment duration,[17,29-39] magnitude of applied force,[33,40-45] direction of tooth movement,[27,38-39,41,46-49] amount of apical displacement,[30,35] and method of force application (continuous vs intermittent,[11,12,42,50-54] type of appliance,[55-57] and treatment technique[16,18,24,25,38,46,57-62]).

Individual susceptibility is considered a major factor in determining RR potential with or without orthodontic treatment.[30,63,64] Patient-related risk factors include: previous history of RR[55,64-66]; tooth-root morphology, length, and roots with developmental abnormalities[5,13,15,19,20,27,35-7,67-71]; genetic influences[3,4,15,64,72-74]; systemic factors[75-78] including drugs (nabumetone),[79] hormone deficiency, hypothyroidism, hypopituitarism[80-83]; asthma[54,84]; root proximity to cortical bone[27,29,85]; alveolar bone density[29,86-88]; chronic alcoholism[89]; previous trauma[12,20,24,54,64-66,90-92]; endodontic treatment[13,49,54,65,66,93,94]; severity and type of malocclusion[13,15,20,27,30,31,34,45,64,95,96]; patient age[1,11,12,14,17,31,35,36,97-99]; and sex.[4,5,15,31,35,45,66,85,100]

Several reviews[2,23,54,55,63] and a meta-analysis[30] examined orthodontics and RR. However, they were not systematic in nature, and the meta-analysis utilized only a Medline search, was restricted to the English language and central incisors, and included retrospective, nonrandomized controlled trials.[30] This systematic review was designed to be more comprehensive in the search method and more restrictive regarding quality measures. It was expected that variables relating orthodontic treatment to RR would be identified. By combining the results from clinical trials, we believed that a stronger evidence-based approach to RR associated with orthodontic tooth movement would provide important guidelines for contemporary clinical practice.

The purpose of this article was to report the results from a rigorous systematic review of scientific literature that relates EARR in patients with fixed orthodontic appliances.

MATERIAL AND METHODS

The first phase of the meta-analysis involved the development of a specific protocol and research question. Table I outlines the Population Intervention Control Outcome (PICO) format used and the null hypotheses. The methods for this review were based on the guidelines of the Cochrane Database of systematic reviews.[101] The primary objective of this review was to evaluate the effect of orthodontic treatment on RR. The secondary objective was to examine the effects of systemic conditions and specific orthodontic mechanics on the rate and severity of RR.

For this review, we located citations to relevant trials in journals, dissertations, and conference proceedings by searching appropriate databases. Detailed search strategies were developed for each database used to identify studies (published and unpublished) to be considered for inclusion. Table II lists the databases searched in this review. To locate additional studies, reference lists of review articles and all included studies were checked. Requests were also sent to relevant professional organizations to identify unpublished and ongoing studies. Hand searches were undertaken to locate published material not indexed in available databases.

Table I. PICO format and null hypothesis

PICO format	
Population	Patients with no history of RR
Intervention	Comprehensive orthodontics
Comparison	People who did not have orthodontic treatment; no teeth were moved orthodontically
Outcome	EARR
Null hypotheses	

1. There is no difference in the incidence and severity of RR between patients, with no history of RR, undergoing comprehensive orthodontic treatment and subjects not treated orthodontically.
2. There is no difference in the incidence and severity of RR between patients, with no history of RR, undergoing comprehensive orthodontic treatment whose teeth are moved with different techniques.

No restrictions were placed on year, publication status, or language of the trials. Translations of foreign-language articles were obtained by contacts in the College of Dentistry at Ohio State University.

Two reviewers (B.W. and K.W.L.V.) independently examined and coded the studies that were identified by the above methods. Trials appropriate to be included in the review were randomized controlled trials (RCTs) fulfilling certain criteria concerning study design, participant characteristics, intervention characteristics, RR outcome, and comparison group. Details about the selection criteria are given in Table III.

The same reviewers extracted data independently, using specially designed data-extraction forms, which were piloted on several articles and modified as required. Any disagreement was discussed and a third reviewer consulted when necessary. All authors were contacted for clarification of missing information. Data were excluded until further clarification became available or if agreement could not be reached. All studies meeting the inclusion criteria then underwent validity assessment and data extraction. Studies rejected at this or subsequent stages were recorded, with the reasons for exclusion listed.

The 2 reviewers evaluated the quality of the trials included in the review independently by assessing 4 main criteria: method of randomization, allocation concealment, blinding of outcome assessors, and completeness of follow-up. Additional minor criteria were examined, including baseline similarity of the groups, reporting of

Table II. Databases included in the systematic review

Databases of published trials
MEDLINE searched via PubMed (1950-October 2008)
EMBASE searched via www.embase.com (1974-October 2008)
Cochrane Database of Systematic Reviews (Cochrane Reviews) searched via The Cochrane Library (October 2008)
Cochrane Cental Register of Controlled Trials (CENTRAL) searched via The Cochrane Library (October 2008)
Cochrane Oral Health Group Trials Register searched via The Cochrane Library (October 2008)
WEB OF SCIENCE searched via www.isiknowledge.com (1975-October 3rd 2008)
EBM Reviews (Cochrane Database of Systematic Reviews, ASP Journal Club, DARE, and CCTR) searched via www.ovid.com (1991- October 2008)
Computer Retrieval of Information on Scientific Project searched via www.crisp.cit.nih.gov (1978 - October 2008)
On-Line Computer Library Center searched via www.oclc.org/home (1967- October 2008)
Google Index to Scientific and Technical Proceedings searched via www.isinet.com/isi/products/indexproducts/istp (October 2008)
LILACS (Latin American and Caribbean Center on Health Sciences Information) searched via www.bireme.br/local/Site/bireme/I/homepage.htm (1982 to October 2008)
PAHO searched via www.paho.org to October 3rd 2008
WHOLis searched via www.who.int/library/databases/en to October 3rd 2008
BBO (Brazilian Bibliography of Dentistry) searched via bases.bireme.br/cgibin/wxislind.exe/iah/online (1966-October 2008)
CEPS (Chinese Electronic Periodical Services) searched via www.airiti.com/ceps/ec_en/ to October 3rd 2008
Databases of dissertations and conference proceedings
Conference materials searched via www.bl.uk/services/bsds/dsc/conference.html; October 3, 2008
Cochrane Cental Register of Controlled Trials (CENTRAL) searched via the Cochrane Library (October 2008)
ProQuest Dissertation Abstracts and Thesis database searched via www.lib.umi.com/dissertations (1986 to October 2008)
Databases of research registers
TrialCentral searched via www.trialscentral.org on October 3, 2008
National Research Register (United Kingdom) searched via www.controlled-trials.com (1998-October 2008)
www.Clinicaltrials.gov, October 3, 2008
Grey literature
SIGLE (System for Information on Grey Literature in Europe) searched via http://opensigle.inist.fr/, 1980 to October 2005

eligibility criteria, measure of the variability of the primary outcome, and sample size calculation. Details about the assessment criteria are given in Table IV.

Statistical analysis

To assess reviewer agreement with respect to the methodologic quality, a kappa statistic was calculated. One reviewer entered that data into Review Manager (version 5.0, Cochrane Collaboration, Boston, Mass).

Quantitative synthesis of data from many studies was to be carried out according to the procedures recommended by the Cochrane Collaboration.[101]

RESULTS

The electronic and hand searches retrieved 921 unique citations, which were entered into a QUORUM flow chart (Fig) to illustrate the path for selecting the final trials. After evaluating titles and abstracts, 144 full articles were obtained (2 articles could not be located). After evaluating the full texts and querying primary authors, we determined that 13 articles, describing 11 trials, fulfilled the criteria for inclusion. Summary details of the studies examined are recorded in Table V. Because these studies used different methodologies and reporting strategies, it was impossible to undertake a quantitative synthesis. A qualitative analysis is therefore presented; it excluded retrospective studies because these are observational and could have been subject to selection bias. Although there are many statistical methods to minimize selection bias, no method unequivocally eliminates it. Thus, retrospective studies (even well-designed ones) do not provide comparative evidence equivalent to that of randomized trials. We chose to include this information in our review by informally comparing the results of the randomized trials to those of key observational studies in our discussion.

Methodologic quality

The assessments for the 4 main methodologic quality items are shown in Table VI. A study was assessed to have a high risk of bias if it did not receive a "yes" in 3 or more of the 4 main categories, a moderate risk if 2 of the 4 did not receive a "yes," and a low risk if randomization, assessor blinding, and completeness of follow-up were considered adequate.

After examination of the studies and follow-up contacts with the authors, if necessary and as noted in Table VI, the method of randomization was considered adequate for 10 of the 11 trials,[20,40,41,43,45,47,62,91,102,103] but the method of allocation concealment was adequate in only 4 of these.[20,47,91,103] The method of randomization and allocation concealment were inadequate or unclear for the remaining 7 articles.[40,41,43,45,50,62,102] Blinding for outcome evaluation was reported in 5 trials.[20,46,62,91,103] The reporting and analysis of withdrawals and dropouts was considered adequate in all 11 trials.[20,40,41,43,45,47,50,62,91,102,103] Five studies were assessed to have low risk of bias, 5 had moderate risk of bias, and 1 had the potential for a high risk of bias.[50]

The minor methodologic quality criteria examined are shown in Table VII. Six studies fulfilled all the minor methodologic quality criteria.[40,41,43,45,62,91] Sample size was justified in 6 of the 11 trials.[40,41,43,45,62,91] Five studies made comparisons to assess the comparability of

Table III. Criteria for selecting studies to be included in the meta-analysis

Criteria category	*Definition*
Study design	Trials should be RCTs (published or unpublished) comparing root length before and during or after treatment in human subjects; split-mouth trials were eligible if randomization was used.
Participants	Trials included could involve subjects or teeth in the same person of any age, sex, or ethnicity who had orthodontic treatment with fixed appliances.
Intervention	Trials could involve interventions of continuous vs noncontinuous forces, differing directions of tooth movement, light vs heavy forces, differing durations of treatment, differing distances of tooth movement, different types of orthodontic appliances.
Control	Trials could involve patients or teeth in the same subject (including the split-mouth technique) not subjected to orthodontic force either through a placebo, bracket placement but no activation, or absence of intervention.
Outcome	Trials included should record the presence or absence of EARR by treatment group at the end of the treatment period. Secondary outcomes include the severity and extent of RR between experimental and control groups assessed either directly with histology or indirectly with a radiograph technique, and patient-based outcomes such as perception of RR, further complications (mobility, tooth loss), and quality-of-life data.

the experimental and control group at baseline.[20,62,91,102,103] Four studies were considered comparable at baseline because they had a split-mouth design with intraindividual controls.[40,41,43,45] Comparability at baseline for Han et al[47] was considered adequate since there was an intraindividual control for the experimental groups, and control teeth were randomly selected (same age and orthodontic treatment plan as the experimental subjects). The study by Acar at al[50] was not comparable at baseline because there was an intraindividual control for both experimental groups, but the control teeth were not randomly selected (same age and orthodontic treatment plan as the experimental subjects). Ten studies had clear inclusion and exclusion criteria.[20,40,41,43,45,47,62,91,102,103] All studies estimated measurement error.[20,40,41,43,45,47,50,62,91,102,103]

The kappa scores and percentage agreements between the 2 raters assessing the major methodologic qualities of the studies were the following: randomization 1.0, 100%; concealment 0.72, 82%; blinding 0.91, 95%; and withdrawals 1.0, 100%.

The included studies were grouped into 11 comparisons according to the clinical questions of interest.

Discontinuous vs continuous force

Acar et al[50] compared a 100-g force with elastics in either an interrupted (12 hours per day) or a continuous (24 hours per day) application. Teeth experiencing orthodontic movement had significantly more RR that control teeth. Continuous force produced significantly more RR than discontinuous force application.

We have some reservations about the reliability of this study's results and were unable to contact the original author to clarify the methodology; based on the information available, the risk of bias was judged to be high. It only met 1 major and 1 minor methodologic criteria.

Removable thermoplastic appliance vs fixed light and heavy force

Barbagallo et al[41] compared forces applied with removable thermoplastic appliances (TA) and fixed orthodontic appliances. The results showed that teeth experiencing orthodontic movement had significantly more RR than did the control teeth. Heavy force (225 g) produced significantly more RR (9 times greater than the control) than light force (25 g) (5 times greater than the control) or TA force (6 times greater than the control) application. Light force and TA force resulted in similar RR cemental loss.

This study was judged to have a moderate risk of bias, since patients were randomly allocated to the experimental and control groups, but the allocation was not concealed and the assessors not blinded to treatment groups. All minor methodologic criteria were met.

Light vs heavy continuous forces

Four split-mouth studies from the same research group compared fixed orthodontic light (25 g) continuous force with fixed heavy (225 g) continuous force in patients needing premolar extractions to relieve crowding or overjet. Three studies applied a buccal tipping force,[41,43,45] and 1 used an intrusive force.[40]

With the exception of a light-force group in a study by Chan and Darendeliler,[45] all teeth experiencing orthodontic movement had significantly more RR than the control teeth.[40,41,43] Chan and Darendeliler[45] found the mean volume of the resorption craters in the light-force group was 3.49 times greater than in the control group (not significant). All studies found that heavy forces produced significantly more RR than light forces or controls.[40,41,43,45] Chan and Darendeliler[45] found that the mean volume of the resorption craters was 11.59 times greater in the heavy-force group than in the control group

Table IV. Criteria for assessing quality components in the trials included in the meta-analysis

Component	*Classification*	*Definition*
Four main quality criteria		
1. Method of randomization (Altman et al[117])	Adequate	Any random sequence satisfying the CONSORT criteria.
	Inadequate	Alternate assignment, case record number, dates of birth.
	Unclear	Just the term *randomized* or *randomly allocated* without further elaboration of the exact methodology in the text and unable to clarify with the author.
2. Allocation concealment (Pildal et al[118])	Adequate	Central randomization, opaque sealed sequentially numbered envelopes, numbered coded vehicles implicitly or explicitly described containing treatment in random order.
	Inadequate	Allocation by alternate assignment, case record number, dates of birth, or open tables of random numbers.
	Unclear	No reported negation of disclosing participants' prognostic data to central office staff before clinician obtains treatment assignment; no reported information on whether allocation sequence is concealed to central staff before a participant is irreversibly registered and no assurance that the sequence is strictly sequentially administered. Unclear in the text and unable to clarify with the author.
	Not used	No method of allocation concealment used.
3. Blinding of outcome assessors	Yes	Outcome assessors did not know which group to which the participants were randomized.
	No	Outcome assessors could assume to which group the participant had been randomized.
	Unclear	Unclear in the text and unable to clarify with the author.
4. Completeness to follow-up (Altman et al[117])	Yes	Numbers in the methods and results were the same or not the same but with all dropouts explained.
	No	Numbers in the methods and results were not the same, and dropouts were not explained.
	Unclear	Unclear in the text and unable to clarify with the author.
Minor criteria		
1. Baseline similarity of groups	Yes	
	No	Groups were not similar at baseline; no comparison between groups at baseline was made.
	Unclear	Unclear in the text and unable to clarify with the author.
2. Reporting of eligibility criteria	Yes	
	No	No clear eligibility criteria.
	Unclear	Unclear in the text and unable to clarify with the author.
3. Measure of variability of primary outcome	Yes	
	No	
	Unclear	Unclear in the text and unable to clarify with the author.
4. Sample size calculation	Yes	
	No	Sample size calculation was not done.
	Unclear	Unclear in the text and unable to clarify with the author.

(significant). Heavy forces in both compression and tension areas produced significantly more RR than in regions under light compression and light tension forces.

Barbagallo et al[41] also found that heavy force produced significantly more RR (9 times greater than the control) than light force (5 times greater than the control).

In contrast to the other studies in this section, Harris et al[40] administered intrusive forces. The results showed that the volume of RR craters after intrusion was directly proportional to the magnitude of the intrusive force. A statistically significant trend of linear increase in the volume of the RR craters was observed from control to light (2 times increased) to heavy (4 times increased) groups.

All 4 studies were judged to have a moderate risk of bias, since only 2 major methodologic criteria were met. All minor methodologic criteria were met.

Intrusive vs extrusive force

Han et al[47] found that RR from extrusive force was not significantly different from the control group. Intrusive force significantly increased the percentage of resorbed root area (4 fold). The correlation between intrusion or extrusion and RR in the same patient was $r = 0.774$ ($P = 0.024$).

This study was judged to have a low risk of bias because all major methodologic criteria were met. Minor

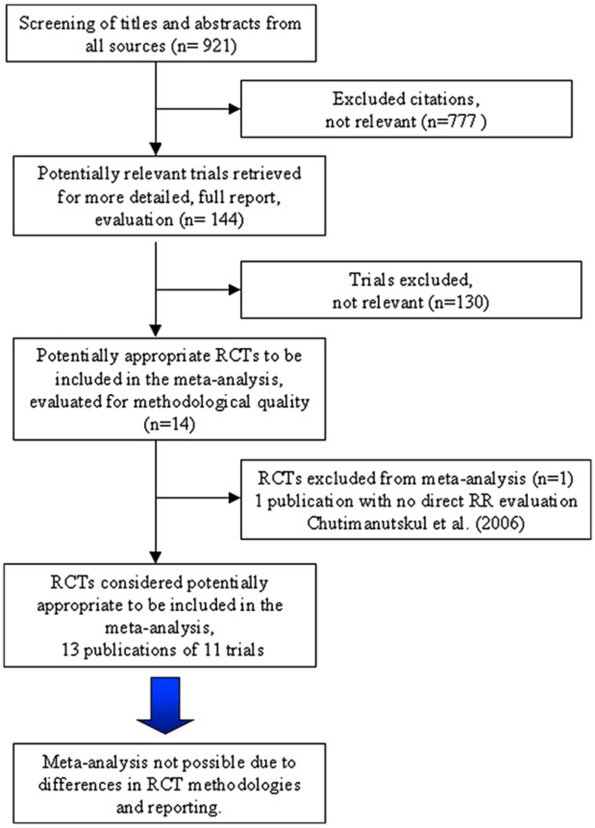

Fig. QUOROM flow diagram of the citations retrieved by titles and abstracts and trials evaluated in full text.

methodologic criteria, except sample size calculation, were met.

As mentioned previously, Harris et al[40] found that the volume of RR craters after intrusion was directly proportional to the magnitude of the intrusive force. This study was judged to have a moderate risk of bias.

Archwire sequence

Mandall et al[91] compared 3 orthodontic archwire sequences in terms of patient discomfort, RR, and time to working archwire. All patients were treated with maxillary and mandibular preadjusted edgewise appliances (0.022-in slot), and all archwires were manufactured by Ormco (Amersfoort, The Netherlands). The results showed no statistically significant difference between archwire sequences, for maxillary left central incisor RR (F ratio, $P = 0.58$). There was also no statistically significant difference between the proportion of patients with and without RR between archwire sequence groups (chi-square = 5, $P = 0.8$, df = 2). This study was well designed and considered unlikely to have significant bias. It was the only study to fulfill all methodologic quality assessment criteria.

Effect of a treatment pause in patients experiencing OIRR

Levander et al[102] investigated the effect of a pause in active treatment on teeth that had experienced apical RR during the initial 6-month period with fixed appliances. All patients were treated with edgewise 0.018-in straight-wire appliances. The results showed that the amount of RR was significantly less in patients treated with a pause (0.4 ± 0.7 mm) than in those treated with continuous forces without a pause (1.5 ± 0.8 mm). No statistically significant correlations were found between RR and Angle classification, trauma history, extraction treatment, time with rectangular archwires, time with Class II elastics, or total treatment time. The study was rated as having a moderate risk of bias, because it fulfilled only 2 major criteria, and there was no a priori sample size calculation. We were unable to contact the author to clarify the allocation concealment and assessor blinding.

Straight wire vs standard edgewise

Reukers et al[103] compared the prevalence and severity of RR after treatment with a fully programmed edgewise appliance (FPA) and a partly programmed edgewise appliance (PPA). All FPA patients were treated with 0.022-in slot Roth prescription (“A” Company, San Diego, Calif), and misplaced brackets were rebonded. All PPA patients were treated with 0.018-in slot Microloc brackets (GAC, Central Islip, NY), and the archwires were adjusted for misplaced brackets. Results showed no statistically significant differences in the amount of tooth root loss (FPA, 8.2%; PPA, 7.5%) or prevalence of RR (FPA, 75%; PPA, 55%) between the groups. This study was well designed and considered unlikely to have significant bias, but it involved variations of 2 variables—slot size and appliance programming—so there could have been undetected interactions.

Trauma vs no trauma

Three studies evaluated the effect of previous trauma (but not EARR) on OIIRR during orthodontic treatment.[20,91,102]

Brin et al[20] showed that incisors with clinical signs or patient reports of trauma had essentially the same prevalence of moderate to severe OIIRR as those without trauma. Mandall et al[91] reported no evidence of incisor trauma and RR. Levander et al[102] also showed no statistically significant correlations between RR and trauma history.

Table V. Characteristics of included studies

Study	Acar et al[50]
Methods	RCT; split-mouth design
Participants	22 first premolars from 8 patients; ages, 15-23 y; 6 control patients, ages, 14-20 y
Interventions	Continuous and discontinuous 100-g force application
Outcomes	Extracted premolars—composite electron micrographs were digitized and amount of root resorbed area calculated, visual assessment of apical morphology and EARR severity.
Notes	9-week treatment period, no withdrawals, no assessor blinding
Allocation concealment	Unclear
Study	Barbagallo et al[41]
Methods	RCT; split-mouth design
Participants	54 maxillary first premolars from 27 patients, 15 female, 12 male; ages, 12.5-20 y; mean, 15.3 y
Interventions	TA vs control, TA vs 225-g continuous force, TA vs 25-g continuous force
Outcomes	Extracted premolars—x-ray microtomography measuring the amount of RR in cubed root volume.
Notes	8-week treatment period, no withdrawals, no assessor blinding
Allocation concealment	No
Study	Brin et al[20]
Methods	RCT; retrospective collection of original data
Participants	138 children with Class II Division 1 malocclusions (overjet $>$7 mm)
Interventions	1-phase treatment vs phase 1 with headgear or bionator followed by phase 2 treatment of comprehensive orthodontics
Outcomes	Length of treatment, trauma, root development/timing of treatment, EARR, root morphology
Notes	Withdrawals accounted for, adequate assessor blinding
Allocation concealment	Computer randomization, e-mailed to research associate
Study	Chan and Darendeliler[43]
Methods	RCT; split-mouth design
Participants	20 maxillary first premolars from 10 patients, intraindividual controls
Interventions	Light (25 g) or heavy (225 g) continuous force vs control
Outcomes	Extracted premolars—volumetric measurement of RR craters via scanning electron microscope, measured in mean volume x 10^5 μm^3
Notes	4-week treatment period, no withdrawals, no assessor blinding
Allocation concealment	No
Study	Chan and Darendeliler[44,45]
Methods	RCT; split-mouth design
Participants	36 premolars in 16 patients, 10 boys, 6 girls; ages, 11.7-16.1 y; mean, 13.9 y; intraindividual controls
Interventions	Light (25 g) or heavy (225 g) continuous force vs control
Outcomes	Extracted premolars—volumetric measurement of RR craters via scanning electron microscope, measured in mean volume x 10^6 μm^3, and to quantify by volumetric measurements the extent of RR in areas under compression and tension
Notes	4-week treatment period, no withdrawals, no assessor blinding
Allocation concealment	No
Study	Han et al[47]
Methods	RCT; split-mouth design
Participants	18 maxillary first premolars from 9 patients, 5 female, 4 male; ages, 12.7-20 y; mean, 15.3 y; 11 control teeth were obtained from 6 randomly selected patients aged 12-20 y
Interventions	Intrusion vs extrusion via 100-g continuous force
Outcomes	Extracted premolars—RR area was calculated as percentage of total root area via scanning electron microscope and visually assessed qualitatively
Notes	8-week treatment period, control teeth extracted before orthodontic treatment, no withdrawals, observers were blinded
Allocation concealment	Yes, randomization computer program, results mailed to operator

Table V. Continued

Study	Harris et al[40]
Methods	RCT; split-mouth design
Participants	54 maxillary first premolars from 27 patients, 12 boys, 15 girls; ages, 11.9-19.3 y; mean, 15.6 y
Interventions	Heavy (225 g) continuous force vs control; light (25 g) continuous force vs control; light (25 g) vs heavy (225 g) continuous force
Outcomes	Extracted premolars—volumetric assessment of RR crater magnitude and location
Notes	4-week treatment period, no withdrawals, no assessor blinding
Allocation concealment	No
Study	Levander et al[102]
Methods	RCT
Participants	40 patients, 62 maxillary incisors, with initial RR during orthodontics, 15 boys, 25 girls; ages, 12-18 y; mean, 15 y
Interventions	Planned treatment vs 2-3 month discontinuation of orthodontic treatment and then planned treatment
Outcomes	Periapical radiographic assessment of maxillary incisor root length
Notes	Patients randomized 6 months into treatment after identification of RR, no withdrawals
Allocation concealment	Unclear
Study	Mandall et al[91]
Methods	RCT—throwing an unweighted die, block randomization
Participants	154 patients, ages, 10-17 y, randomized 6 months into treatment after identification of RR, no withdrawals
Interventions	3 different archwire sequences
Outcomes	Patient discomfort at each wire change and in total, RR (root length) of maxillary left central incisor assessed by periapical radiography, time to reach maxillary and mandibular working archwire (0.019 x 0.025-in stainless steel) in months, number of patient visits
Notes	All withdrawals accounted for, blinded assessors for RR
Allocation concealment	Adequate—opaque envelopes
Study	Reukers et al[103]
Methods	RCT—balanced treatment allocation via computer
Participants	149 Class II patients, 64 male, 85 female; mean age, 12 y 4 mo (SD, 1 y 2 mo); range, 10 y 7 mo-15 y 8 mo
Interventions	Fully programmed edgewise (straight wire) vs partly programmed (conventional) edgewise
Outcomes	Prevalence and degree of RR seen via periapical radiography via a bisecting angle technique.
Notes	All withdrawals accounted for, blinded assessors for RR
Allocation concealment	Adequate—orthodontist informed by central trial registration
Study	Scott et al[62]
Methods	RCT—balanced treatment allocation via restricted number table
Participants	62 patients, 32 male, 30 female; mean age, 16.27 y, with mandibular irregularities of 5-12 mm, requiring mandibular first premolar extractions
Interventions	Damon3 self-ligating brackets vs Synthesis (Roth prescription) conventionally ligated brackets
Outcomes	Rapidity of tooth alignment; changes in root length; changes in arch dimension, measured via lateral cephalograms and long-cone periapical radiographs
Notes	All withdrawals accounted for, blinded assessor for RR, 95% power
Allocation concealment	Unclear

The studies by Brin et al[20] and Mandall et al[91] were judged to have low risk of bias, whereas that of Levander et al[102] was judged to have moderate risk of bias.

Teeth with unusual morphology

Brin et al[20] examined the severity of RR in teeth with unusual morphology. The results showed that teeth with roots having unusual morphology before treatment were not significantly more likely to have moderate to severe OIIRR than those with more normal root forms. This study was judged to have a low risk of bias because it fulfilled all major methodologic criteria. However, there was no a priori sample size calculation, since this was a secondary endpoint for the RCT.

Table VI. Quality assessment—major criteria

Study	*Randomization*	*Allocation concealed*	*Assessor blinding*	*Dropouts described*	*Risk of bias*
Acar et al[50]	No	Unclear	Unclear	Yes	High
Barbagallo et al[41]	Yes	No	No	Yes	Moderate
Brin et al[20]	Yes	Yes	Yes	Yes	Low—retrospective
Chan and Darendeliler[43]	Yes	No	No	Yes	Moderate
Chan and Darendeliler[44,45]	Yes	No	No	Yes	Moderate
Han et al[47]	Yes	Yes	Yes	Yes	Low
Harris et al[40]	Yes	No	No	Yes	Moderate
Levander et al[102]	Yes	Unclear	Unclear	Yes	Moderate
Mandall et al[91]	Yes	Yes	Yes	Yes	Low
Reukers et al[103]	Yes	Yes	Yes	Yes	Low
Scott et al[62]	Yes	Unclear	Yes	Yes	Low

Table VII. Quality assessment—minor criteria

Study	*Sample justified (size)*	*Baseline comparison*	*I/E criteria*	*Method error*
Acar et al[50]	No	No	Unclear	Yes
Barbagallo et al[41]	Yes	Yes	Yes	Yes
Brin et al[20]	No	Yes	Yes	Yes
Chan and Darendeliler[43]	Yes	Yes	Yes	Yes
Chan and Darendeliler[44,45]	Yes	Yes	Yes	Yes
Han et al[47]	No	Yes	Yes	Yes
Harris et al[40]	Yes	Yes	Yes	Yes
Levander et al[102]	No	Yes	Yes	Yes
Mandall et al[91]	Yes	Yes	Yes	Yes
Reukers et al[103]	Unclear	Yes	Yes	Yes
Scott et al[62]	Yes	Yes	Yes	Yes

I/E, Inclusion and exclusion.

Two-phase vs 1-phase Class II treatment

Brin et al[20] examined the effect of 2-phase vs 1-phase Class II treatment on the incidence and severity of RR. The results showed that children treated in 2 phases with a bionator followed by fixed appliances had the fewest incisors with moderate to severe OIIRR, whereas children treated in 1 phase with fixed appliances had the most resorption. However, the difference was not statistically significant. As treatment time increased, the odds of OIIRR also increased ($P = 0.04$). The odds of a tooth experiencing severe RR were greater with a large reduction in overjet during phase 2. This study was judged to have a low risk of bias because it fulfilled all major methodologic criteria. There was no a priori sample size calculation, since this was a secondary endpoint for the RCT.

Self-ligating vs conventional orthodontic bracket systems

Scott et al[62] investigated the effect of either Damon3 self-ligating brackets or a conventional orthodontic bracket system on mandibular incisor RR. Patients were treated with Damon3 self-ligating or Synthesis (both, Ormco, Glendora, Calif) conventionally ligated brackets with identical archwires and sequencing in all patients. The results showed that mandibular incisor RR was not statistically different (Damon3, 2.26 mm, SD 2.63; Synthesis, 1.21 mm, SD 3.39) between systems. This trial was judged to have a low risk of bias. It fulfilled 3 major methodologic criteria and all minor methodologic criteria. The author was contacted for further information.

Heterogeneity, sensitivity analyses, and publication bias

No meta-analysis, combining more than 1 study, was undertaken; thus, this did not apply.

Secondary outcomes

Other outcomes such as patient's perception of RR, tooth mobility, tooth loss, or quality-of-life data were not recorded in any studies.

DISCUSSION

OIIRR is considered a particularly important sequela of orthodontic treatment. However, only 11 trials were considered appropriate for inclusion in this review, and their protocols were too variable to proceed with a quantitative synthesis. This reflects the state of the published scientific research on this topic.

It is widely accepted that properly executed well-designed RCTs provide the best evidence on the efficacy of health-care interventions. In spite of the considerable amount of OIIRR research in the scientific literature from clinical trials, they were not randomized, prospective, or representative of 24-month comprehensive orthodontic care. Moreover, in many studies, the measurement techniques for OIIRR were not uniform or on similar teeth. Other systematic reviews have also commented on the lack of uniformity for reporting data in the dental literature.[104-106]

The detection of OIIRR has been mainly through radiographs, light microscope, scanning electron microscope, and microcomputed tomography. Clinically, radiographs are an important diagnostic tool in detecting OIIRR, but the varying degrees of magnification and the limitations of 2-dimensional measurement of a 3-dimensional phenomenon make the quantitative value of radiographs questionable and geometrically inaccurate.[15,107,108] Quantitative 3-dimensional volumetric evaluation of RR craters has been found to be a feasible alternative with a high level of accuracy and repeatability.[43,45,109] Future studies should use both accurate, reliable, and valid measurement tools so that meaningful comparisons can be made.

This systematic review included 6 RCTs with split-mouth designs. The results of the quality assessments, the small sample sizes, and the short experimental periods of these studies led to the conclusion that their validity is limited. Each split-mouth study analyzed premolars—teeth not routinely or severely affected by OIIRR. Also, no split-mouth study lasted longer than 9 weeks. We have evidence to suggest that orthodontic force applied to teeth over a short period can produce resorption lacunae without EARR.[110] Longer trials would be more appropriate to evaluate the full effects of orthodontic tooth movement on RR. As a result, the scientific evidence supporting clinical recommendation to reduce OIIRR in patients undergoing fixed orthodontic appliance therapy is insufficient to allow many useful conclusions.

Our results show that teeth experiencing orthodontic movement had significantly more RR than did the control teeth.[40,41,44,45] Heavy forces produced significantly more RR than light forces or in the controls.[40,41,43,45] It is believed that higher forces cause more extensive RR because the rate of lacuna development is more rapid, and the tissue repair process is compromised.[30,40-45] Earlier nonrandomized studies contradict these findings. According to Owman-Moll et al,[111,112] when the force magnitude was doubled and quadrupled from 50 cN, there was no effect on the frequency or severity of RR or on the rate of tooth movement in their experiments. Although individual variations in RR and rates of tooth movement were large, normal individual variations might overshadow the effect of a doubled force magnitude. These results should be interpreted with caution because the selection criteria for the premolars were not strict, and external factors that might predispose teeth to RR were not excluded. Also, the accuracy of the serial sectioning protocol in identifying and measuring all craters was questionable; craters could easily have been partially or even completely missed.[43,44]

We have limited evidence that continuous force produced significantly more RR than interrupted force application.[50] This agrees with the results of studies with less-rigorous designs that found that discontinuous forces resulted in lower RR than the application of a continuous force.[42,51,52] This was believed possible because the pause in the force allows the resorbed cementum to heal and prevents further resorption. This finding contradicts results from an earlier, similar nonrandomized, split-mouth experiment by Owman-Moll et al[53] in which there was no difference in RR between teeth that were moved with either a continuous or an interrupted continuous force. These results should be interpreted with caution, because force decay was evident in the springs used in the continuous-force groups.

Our limited evidence suggests that both light forces and forces from thermoplastic appliances result in similar RR cemental loss, which was significantly more than in the controls.[41] A recent longitudinal study of 100 consecutive Invisalign patients showed no measurable RR (T. Wheeler, DMD, PhD, unpublished data).[113] There is no strong evidence from other studies that investigated this topic, but a case report showed a significant EARR outcome with aligner treatment.[114]

In our systematic review, the studies examining intrusive force applications found significantly increased RR rates compared with the controls.[40,47] RR from extrusive force was not significantly different from the controls.[47] This agrees with previous literature indicating that the greatest damage is observed with intrusive tooth movements, since they concentrate pressure at the tooth apex.[27,38,40,42,46,47] When examining the maxillary central incisors, movements that torque the apex lingually are strongly correlated with RR. In combination, intrusion and lingual root torque are the strongest evidence for causing OIIRR.[46-48]

This systematic review included 5 RCTs examining patients undergoing comprehensive orthodontic treatment. Four of these studies were judged to be of high quality, with a low risk of bias,[20,62,91,103] and 1 was judged to have a moderate risk of bias.[102]

When comparing straight-wire and standard edgewise techniques, no statistically significant differences in the amount of tooth root loss or prevalence of RR were observed between groups.[103] Some have suggested that the Begg technique might cause more harmful effects on the roots.[25,58,59] Other studies suggested that there is no real significant difference between Begg, Tweed, or various straight-wire edgewise techniques.[24,38,46,60,61] Bioefficient therapy with contemporary orthodontic materials produced significantly less RR than simplified standard edgewise or edgewise straight-wire systems. It was believed that, during incisor retraction and finishing, the use of heat-activated and superelastic wires and a smaller rectangular stainless steel wire played roles in this finding.[18]

Historically, it has been accepted that all teeth with a previous history of trauma are more susceptible to OIIRR than healthy control teeth. This was based mainly on observational data and animal studies.[11,12,90] Other investigators reported that teeth with slight to moderate injuries might not have a greater tendency for RR during orthodontic treatment than uninjured teeth.[25] In this systematic review, when examining data from 3 RCTs meeting our inclusion criteria, we found that incisors with clinical signs or patient reports of trauma (but no signs of EARR) had essentially the same prevalence of moderate to severe OIIRR as those without trauma.[20,91,102] There is a lack of RCT data about patients with previously traumatized teeth with RR before orthodontic treatment. Observational data indicate a greater chance that orthodontic movement will enhance the resorptive process in this situation.[25,55,65,66]

We found evidence that teeth with unusual root morphology before treatment were only slightly more likely to have moderate to severe OIIRR than those with normal root forms, but the difference was not statistically significant.[20] Through mostly observational studies, abnormal root shape and other dental anomalies have been reported as risk factors for OIIRR.[15,37,67-69,102] Other investigators found no significant correlation between tooth anomalies and OIIRR,[20,70] or significant correlations between peg-shaped roots or microdontia of lateral incisors and OIIRR.[28]

When comparing conventional edgewise systems with various active and passive self-ligating appliances, Blake et al[16] (case-control study) and Pandis et al[57] (prospective clinical trial) found no statistically significant differences in RR between systems. Our findings in Scott et al agreed that mandibular incisor RR did not differ between self-ligating (Damon3, 2.26 mm, SD 2.63) and conventional (Synthesis, 1.21 mm, SD 3.39) systems.[62]

There is little evidence in the literature for or against our results about archwire sequencing,[91] and 1-phase and 2-phase Class II treatments with respect to OIIRR prevalence or severity.[20]

There is evidence that comprehensive orthodontic treatment causes increased EARR. With the exception of the light-force group in 1 trial,[45] all teeth experiencing orthodontic tooth movement had statistically significant more RR than did the control teeth in the 11 trials included in this review, although individual variations were large.

It is important to advise orthodontic patients of the risks before starting treatment. A significant reduction in root length can cause an unfavorable crown-root ratio of the affected teeth, making them less suitable as abutments and anchorage for prosthetic restorations. Also, apical root loss of 3 mm is equivalent to 1 mm of crestal bone loss, so periodontitis will progress more rapidly to a critical alveolar bone level if it involves teeth with RR.[115]

It was found that RR associated with orthodontic treatment ceases after active treatment.[94] Even extensive RR does not usually affect the functional capacity or greatly compromise the longevity of the teeth. An average-sized, normally shaped maxillary central incisor with no alveolar bone loss during orthodontic treatment with a root shortened by 5 mm will still have 75% of its periodontal attachment remaining (95% of patients); this explains why tooth loss from apical shortening has not been reported in the literature.[115] A retrospective study, in which 100 patients were recalled 14 years after orthodontic treatment, found tooth loss and hypermobility in only 2 patients.[94] A more recent retrospective analysis of patients who had experienced severe RR (root lengths 5.5-18.1 mm), recalled 5 to 15 years after treatment, found that no teeth had mobility scores greater than 1 on Miller's index (crown deviations within 1 mm of normal position), and no teeth had been lost.[116]

Implications for clinical practice

There is evidence that comprehensive orthodontic treatment causes increased incidence and severity of RR, and that heavy forces are particularly harmful. Until more high-quality clinical trials are conducted, we recommend that the best practice is using light forces, especially for intrusive movements.

However, there is no evidence that OIIRR is affected by archwire sequencing, bracket prescription, or self-ligation. There is also little evidence that previous trauma (with no history of EARR) and unusual tooth morphology play roles in increased OIIRR.

During orthodontic treatment, progress radiographs obtained after 6 to 12 months might detect early OIIRR. In patients in whom OIIRR has been identified, there is some evidence that a 2 to 3 month treatment pause (with a passive archwire) decreases further RR.

If severe resorption is identified, the treatment plan should be reassessed with the patient. Alternative options might include prosthetic solutions to close spaces, releasing teeth from active archwires if possible, stripping instead of extracting, and early fixation of resorbed teeth.[54]

After treatment, if severe OIIRR is shown on the final radiographs, follow-up radiographic examinations can be recommended until the resorption has stabilized. Termination of active OIIRR usually occurs after appliance removal. If it continues, sequential root canal therapy with calcium hydroxide might be considered.[63] Caution should be used when retaining the teeth with fixed appliances, since occlusal trauma to the fixed teeth or segments might lead to extreme EARR.[54]

Implications for research

Although the evidence in our conclusions from this systematic review was from 11 RCTs on human subjects, there was still a risk of bias because of their design and heterogeneity when making assumptions. More evidence is required to determine risk factors for identifying those susceptible to EARR and effective ways to decrease its severity and prevalence in orthodontic patients. As new evidence emerges for identifying patients with a genetic susceptibility to RR, we may develop a routine diagnostic test for determining risk and prior probability estimates of RR. There is a need for parallel group studies, with appropriate randomization, allocation concealment, and masking of outcome assessment. They should be based on an estimated sample size calculation to ensure adequate power and be conducted over the full length of orthodontic treatment.

The use of standardized techniques to measure root length and volume before and after treatment should be encouraged to provide a permanent record, allowing before and after comparisons of incidence and severity of RR with assessment blinding, error analysis, and consensus measures. Studies should also assess patient-centered outcomes, including the effect of severe RR on quality of life after treatment and further complications such as mobility and tooth loss. Other factors, such as genetic predisposition and systemic factors, should be assessed, so that we can better understand how individual susceptibility affects the incidence and severity of OIIRR.

CONCLUSIONS

1. Increased incidence and severity of OIIRR is found in patients undergoing comprehensive orthodontic therapy.
2. Heavy force application produced significantly more OIIRR than light force application or control.
3. Other trends from split-mouth studies could not be substantiated because of few subjects and short treatment times.
4. Standard reporting methods of future clinical trials are recommended so that data can be pooled quantitatively and stronger clinical recommendations made.

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