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Research Article

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Is Apical Root Resorption Greater When Using Clear Aligners as Compared to Conventional Fixed Appliances in Adult Patients Following Orthodontic Treatment? A literature Review

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Abstract

Background: *Apical root resorption has been identified as a potential risk/adverse effect of conventional orthodontic treatment, however, with changing dental demand and increasing patient preference for clear aligners therapy, the availability of evidence-based information on its incidence/severity following treatment with either clear aligners or fixed appliance is of relevance to clinical practice in providing guidance on orthodontic treatment risk to patients and therefore contributing to the process of obtaining valid informed consent.*

Objectives: *The aim of this study is to undertake a literature review to establish whether apical root resorption following orthodontic treatment is greater in adult patients treated with clear aligners as compared to conventional fixed appliances, to analyse and appraise the data, to make appropriate recommendations relevant to orthodontic practice and is widely referenced by orthodontists.*

Search Methods: *A systematic literature search of three databases (Medline, Embase, Web of science), Google scholar and a hand search of relevant journals was done.*

Selection Criteria: *Primary research studies high in the hierarchy of evidence that investigated/compared apical root resorption following extraction/non-extraction based orthodontic treatment with fixed appliance or clear aligners in adult patients equal to or greater than 18 years between January 2010 and December 2021 were selected for this systematic review.*

Data Collection and Analysis: *Studies were accessed, duplicates eliminated, data extracted with the use of a customized data extraction form, and quality assessed using a critical appraisals skills programme tool.*

Results: *A total of 67 studies were identified, and after the elimination of duplicates and quality assessment, six studies were selected for review. The Cochrane Rob 2 bias tool was used to assess the risk of bias of the selected studies. Apical root resorption prevalence/severity was measured using two different radiographic methods: 3-Dimesional (CBCT-scan) and 2-Dimensional (panoramic/periapical radiographs).*

Conclusions: *The majority of the studies showed that the severity/prevalence of apical root resorption is less in clear aligners compared to fixed appliance treated patients, however, they are characterized by different baseline malocclusion/treatment duration/modalities, study design flaw, inconsistency in outcome measurement/calculation.*

Due to these limitations, it is difficult to arrive at a conclusion and make recommendations applicable to everyday clinical practice. The clinician should take into consideration factors that increase the risk of apical root resorption such as genetic predisposition, treatment duration, force application (types and location), types of tooth movement, initial malocclusion and extraction/non-extraction-based treatment in deciding on the orthodontic treatment option and gaining patient consent.

Limitations: *The current evidence has a number of limitations including the lack of robust prospective studies on apical root resorption, different methods of outcome measurement and calculation, different baseline malocclusions, the evaluation of apical root resorption in only one treatment modality and short treatment duration which may influence the validity of the study conclusions. A meta-analysis could not be performed due to the heterogeneous outcome recording methods. Further research is recommended.*

Abbreviations

FAs - Fixed appliances
FA - Fixed appliance
CAT - Clear aligner therapy
yrs - Years
n - Number of teeth
ARR - Apical root resorption
m - Male
f - Female
CBCT - Cone beam computer tomography
MeSH - Medical subject headings
T0 - Pre-treatment root length
T1 - Post treatment root length
rRCR - Relative root crown ratio

1. Introduction/Background

Apical root resorption (ARR) is one of the potentially deleterious effects of orthodontic treatment and an important factor for a patient to consider when deciding whether to undergo orthodontic treatment [1]. Along with other predisposing factors such as genetic make-up, excessive orthodontic force and prolonged treatment duration, root resorption may be stimulated by the application of force mechanics during orthodontic tooth movement; this process initiates a series of osteoblastic and osteoclastic activities, resulting in bone or root remodeling (resorption and repair of bone/adjacent root tissue) [2-5]. If repair of resorbed apical cementum or dentine fails to occur, defects or craters appear in this region (Figure 1) [6]. The long-term effect on affected teeth has been judged to be clinically insignificant except when root resorption is severe (greater than 4mm of the original root length is lost), resulting in root shortening (unfavourable crown-root ratio) and an increased risk of tooth mobility (Figure 2) [7]. Regarding the role of orthodontic appliance types in the occurrence and severity of apical root resorption, study results have been varied, especially relating to the two commonly used appliance types namely conventional fixed appliances (FAs) and clear aligners (CAs). Conventional fixed appliances have the advantage of producing predictable and faster results when compared with clear aligners [8]. Historically, these have been the preferred appliance option for most patients requiring orthodontic treatment. Despite this wide acceptance, apical root resorption has been found to affect the teeth of 90% of patients who undergo comprehensive orthodontic treatment with fixed appliances, but the extent has been found to be clinically insignificant [9-11]. Recently, possibly linked to the Covid-19 global pandemic and the advances in tele-dentistry, there has been a surge in the number of patients wishing to have treatment with clear aligners as compared to fixed appliances; this may be due to a demand for aesthetic braces, technological advancements in orthodontics or an increased investment in the commercial aligner market [12,13]. However, one of the main concerns is the need to determine if clear aligners have a greater potential risk of causing apical root resorption than fixed appliances. A radiometric study of the head and face by (2013) found that 7.36 teeth per patient treated with clear aligners showed a measurable reduction in root length [14]. This is further supported by the findings of Liu, et al., (2021) in which the use of volumetric cone beam computer tomography revealed mild-to-moderate root volume loss in most incisors treated using clear aligners. When comparing the two types of appliances, Jianru, et al., (2021) concluded that apical root resorption occurred more with the use of fixed appliances than clear aligners. This is supported by Li, et al., (2020), who reported reduced severity and prevalence of apical root resorption with the use of clear aligners compared with conventional fixed appliances.

Since the last systematic review by Gandhi, et al., (2021), there have been further studies published. Jyotirmay, et al., (2021) reported less apical root resorption with clear aligners compared with fixed appliances however Toyokawa-Speradino, et al., (2021) reported a similar degree of apical resorption in both types of appliances, and this justifies the need for a further review. This literature review aims to identify, appraise, and analyse the most robust currently available evidence, which will be of relevance to clinical practice and provide guidance on orthodontic treatment options to patients who need to be aware of the level of risk of apical root resorption associated with each option and therefore its important contribution in the process of obtaining valid informed consent. The objective is to produce a paper suitable for publication in the European Journal of Orthodontics which has a high impact rating and wide referencing by orthodontists.

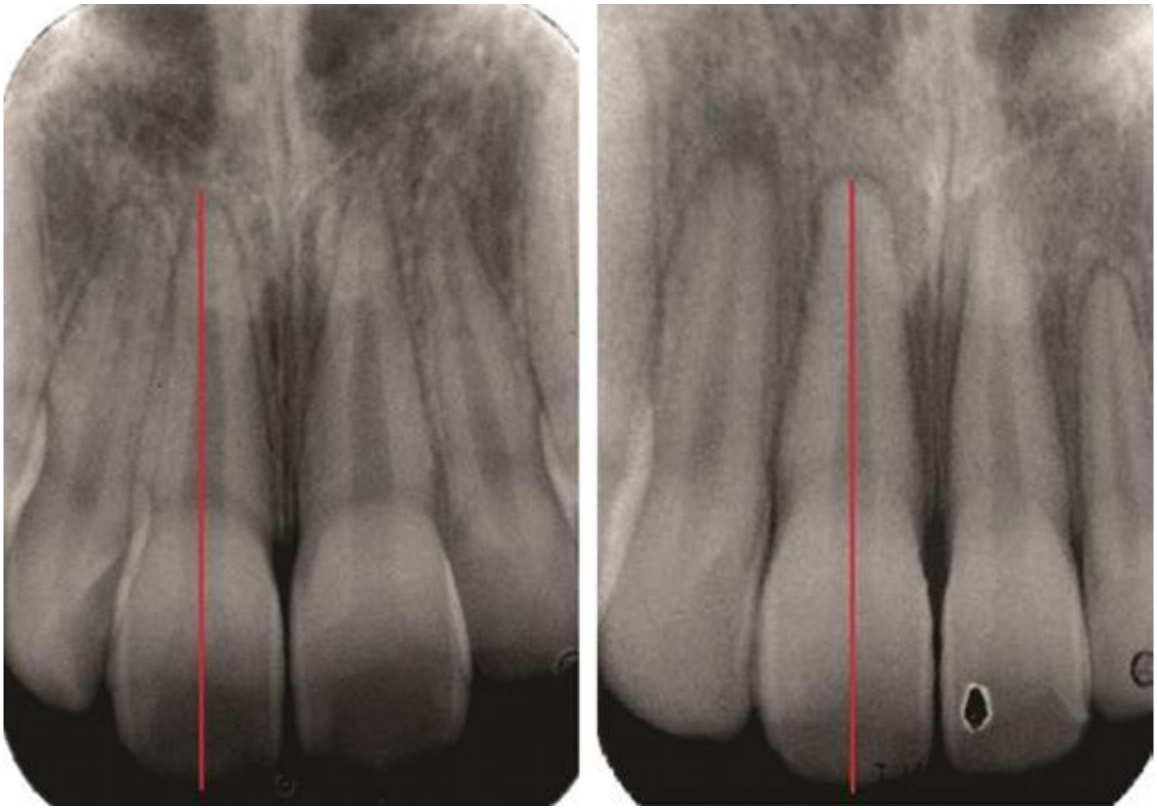

Figure 1: (a) Before orthodontic treatment (a line showing tooth length with no root resorption) and (b) after orthodontic treatment showing reduction in tooth length due to apical root resorption [15]

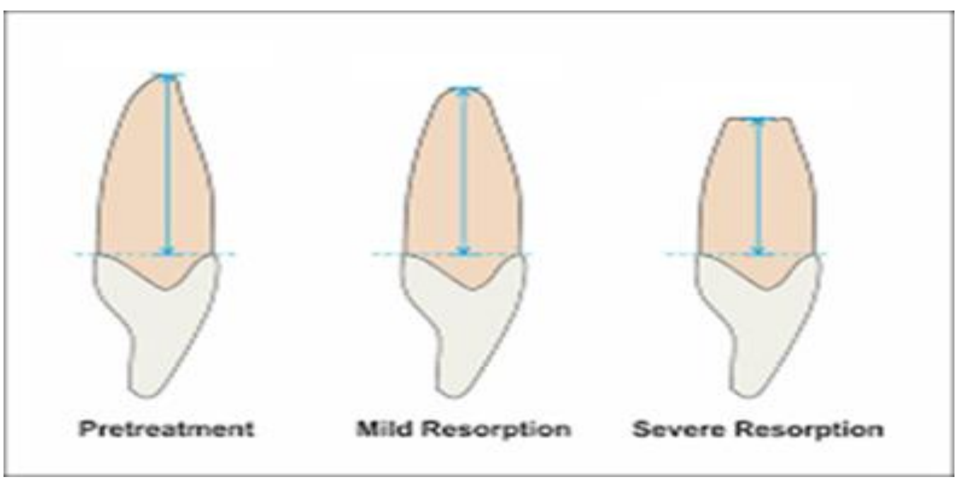

Figure 2: Tooth length pre-orthodontic treatment; post-orthodontic treatment mild and severe apical root resorptions [16]

2. Method

The search question was framed using PICO criteria (Table 1).

		Search terms
P= Population	Adult orthodontic patients, ≥18 years with no restriction on gender, race or country	
I= Intervention	Clear aligners	Clear aligners Aligners Invisalign
C =Comparator	Conventional fixed appliances	Fixed appliances/Orthodontic fixed appliances
O= Outcome	Apical root resorption	Apical root resorption/External apical root resorption.

Table 1: PICO Table

One reviewer searched relevant studies from the following electronic databases: Medline, Embase, Cochrane library and Google scholar. Hand-searching was carried out to avoid exclusion of studies not identified by the electronic database search strategy. The following relevant journals were hand-searched: Journal of Orthodontics, British Dental Journal, American Journal of Orthodontics, and European Journal of Orthodontics. The bibliographies of relevant papers were also reviewed. The search period was from January 2010 to December 2021. This time period witnessed the most widespread use of clear aligners by orthodontists and orthodontic patients.

The search terms were based on key words in the research question and appropriate free text words. Medical subject headings (MeSH) were formed for each key word, some were truncated to allow for a more comprehensive search and retrieval of relevant studies that might have spelled the required key word differently. The free text, medical search terms and truncated key words were combined using Boolean logic operators such as AND, and OR.

Study Selection

Exclusion criteria and inclusion criteria were defined and are listed in (Table 2).

Inclusion criteria	Exclusion criteria
• Primary research studies high in the hierarchy of evidence. (Randomised controlled trials, cohort studies), • Published in English • Between January 2010 and December 2021 • Adult orthodontic patients, ≥18 years with no restriction on gender, race or country • Patients provided with fixed appliances or Clear aligners • Studies addressing apical root resorption	• Systematic reviews and meta-analysis • Non-refereed primary research papers (case series/reports), • In vitro and animal studies • Studies published before January 2010 and after December 2021. • Orthodontic patients below 18 years • Other removable/functional appliances • Other types of tooth resorption

Table 2: Inclusion/Exclusion Criteria

3. Results

Selected studies were accessed, and the search results presented in a Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow chart (Figure 3). Thirty studies were identified from databases and thirty-seven from other sources. Thirty-six duplicate studies were rejected, sixteen articles were rejected at the title stage and five at abstract stage. Full texts of ten papers were screened using the Critical Appraisal Skill Programme Checklist tool (CASP) UK, (2022) and six high-scoring quality papers were accepted for review. The CASP tool is preferred because it is designed for health-related research and is recommended by the World Health Organization and Cochrane research [17].

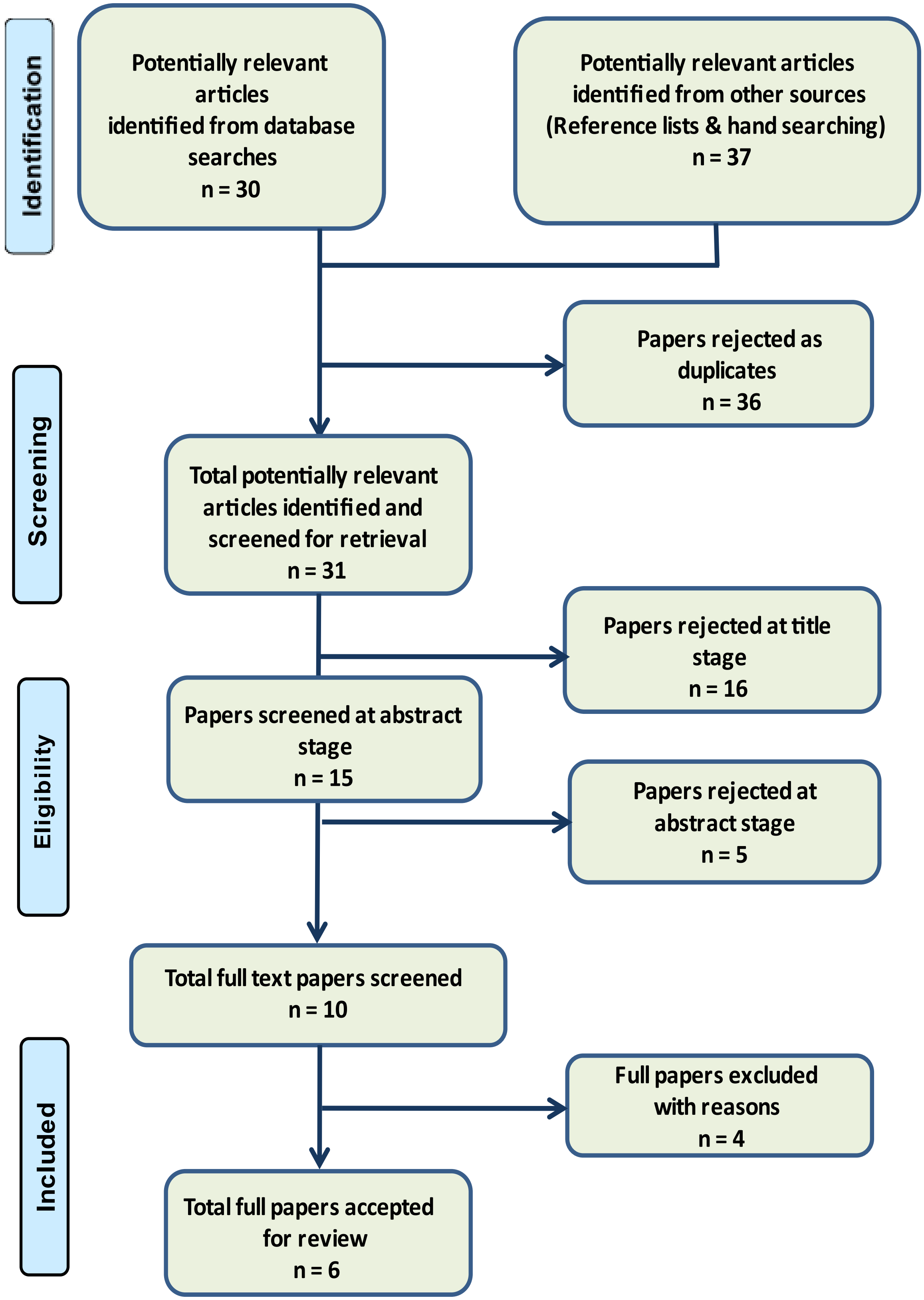

Figure 3: PRISMA flow chart

Data were extracted from the selected papers using a customized data extraction form developed according to the variables required from primary research studies (Table 3). The following information was extracted: authors name/year of publication, study design, sample size, demographic/treatment duration, intervention/comparator, outcome measurement and outcome.

The Cochrane risk of bias tools for randomized control trials (Rob 2) was used to assess the risk of bias of the six papers selected for review [18]. For each study, adequacy of randomization, allocation concealment, blinding, outcome data assessment/reporting and presence of selective reporting were assessed (Table 4).

Author/year of Publication	Toyokawa *et al.* (2021)	Liu, W. *et al* (2021)	Jyotirmay *et al.* (2021)	Li, Yuan *et al.* (2020)	Jianru *et al.* (2018)	Gay *et al.* (2017)
Study design	Randomised clinical trial (RCT)	Retrospective cohort study	Retrospective cohort study	Retrospective Cohort study	Retrospective cohort study	Prospective Radiometric study
Participants /Sample size	40 subjects CAT-20 subjects; (n= 160 incisors) FA-20 subjects; (n = 160 incisors) Non-extraction, Class I Malocclusion patients	40 subjects (*n* = 320; upper and lower anterior) (no attachments (n = 265) or optimized attachments (n = 55). All Patients had Class II malocclusion and 50% had extraction (4 premolars extraction non-extraction patients	110 subjects (n=576; upper and lower incisor, upper and lower canines). FA-55 subjects (n=288). CAT-55 subject(n=288) Extraction/Non-extraction cases	70 subjects (*n* = 373; upper and lower anterior. FA-35 subjects CAT-35 subjects Class II and III. Extraction and Non-extraction cases	80 subjects (*n* = 640; upper and lower anterior, FA-40 subjects (n= 320 incisors CAT-40 subjects (n= 320 incisors) Class I, II and III Non-Extraction case	71 subjects, n=1083; upper and lower anterior, canines, upper first premolars and molars. Class I with crowding (arch length discrepancy-6mm) Non-extraction cases
Demographic and treatment duration	Mean age: CAT-23.6±5.65 yrs. FA-20.6±4.51yrs Treatment duration-6months	Mean age: 24.1 ±5.8% yrs. (m=20; f=20) Treatment duration: -21.4± 7.24	Mean age: FA-23.71 ± 6.37 yrs. (m=23; f= 32) CAT-21.62 ± 3.58 yrs. (m=21; f=34 Treatment duration-30months	Mean age: 23.61 ± 7.03 yrs. (m-21; f- 49) Treatment duration; -FA-22.5±6.47 CAT-24.7±7.48	Mean age: CAT-21.80±5.11 yrs. FA-23.28±5.60yrs. (m-20; f-60) Treatment duration: -FA-20.8± 4.51; CAT-22.1±5.29	Mean age-32.8±12.7yrs. Age range-18-71yrs. (m-25, f-46) Treatment duration-14months
Intervention /Comparator	CAT (Smart-Track, Invisalign) and FA	CAT (Invisalign)	CAT (Inline aligners) and FA	CAT and FA	CAT and FA	CAT (Invisalign)
Outcome Measurement	Periapical radiograph	Volumetric CBCT Scan	CBCT Scan	CBCT Scan	Panoramic radiograph	Panoramic Radiograph
Outcome	ARR seen in 2.88% of the root length leaving 97.12% unaffected. -Significant difference in intra-group comparison with (T1−T0) ranging from −0.52 to −0.88 mm in the FA group and from −0.52 to −0.85 mm in the CAT group	incisors showed root volume loss of 11.48 ± 6.70 $mm^{3,}$ -Prevalence of severe resorption was 0.63% -The severity, a reduction of root volume <10% was found in 70.9% (n = 227), >10% - 20% in 28.4% (n = 91) and >20% in 0.6% (n = 2) of the teeth were affected	Mean value of ARR in CAT group was (1.12 ± 1.34), was significantly less than that of FA group (1.51 ± 1.34) (P<0.001)	Prevalence of ARR in the CAT (56.3%) was significantly less than that in the FA group (82.11%) (*P* < 0.001) Severity of ARR in the CAT group (0.13 ± 0.47 mm) was clinically and statistically significantly less than that in the FA group (1.12 ± 1.34 mm) (*p* < 0.001)	Mean value of ARR in CAT group was 5.13 ± 2.81%, which was significantly less than that of FA group (6.97 ± 3.67%)	A minimum of one tooth affected with a reduction of root length; 6.4 ± 2.3 teeth per patient. A reduction of the post-treatment root length (rRCR < 100%) seen in 41.8% of the 1083 (n=453); a reduction of >0%- 10% in 26%(n=281); a reduction of >10%- 20% in 12%(n=132); a reduction of >20% in 3.7% (*n* = 40)

FA-Fixed appliance, CAT-Clear aligner therapy, yrs.-years, n-number of teeth, ARR-Apical root resorption, m=Male, f=female, CBCT-Cone beam computer tomography, T0-pre-treatment root length, T1-post treatment root length, rRCR-relative root crown ratio.

Table 3: Data Extraction Table

	Random sequence generation	Allocation concealment	Blinding of participants/ personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
1 Toyokawa *et al.,* (2021)	Low risk	Low risk	High risk	Low risk	Low risk	Low risk	Low risk
2 Liu *et al.,* (2021)	Low risk	Unsure	Low risk	Low risk	Low risk	Low risk	Unsure
3 Jyotirmay *et al.,* (2021)	Low risk	Unsure	Low risk	Low risk	Low risk	Low risk	Unsure
4 Li *et al.,* (2020)	Low risk	Unsure	Low risk	Low risk	Low risk	Low risk	Unsure
5 Jianru *et al.,* (2018)	Low risk	Unsure	Unsure	Low risk	Low risk	Low risk	Unsure
6 Gay *et al.,* (2017)	Unsure	Unsure	High risk	Low risk	Low risk	Low risk	Unsure

-Low risk -High risk -Unsure

Table 4: Rob2 Cochrane Bias Table

4. Discussion

Following the search strategy using the inclusion/exclusion criteria, and CASP quality assessment, one randomised control trial was selected [19]. The other studies selected were retrospective cohort studies and Gay, et al., (2018) a prospective cohort study [20-23]. Toyokawa, *et al*., (2021); Li, *et al*., (2020); Jyotirmay, *et al.,* (2021) and Jianru, *et al.,* (2018) evaluated and compared apical root resorption (ARR) occurrence in the FA and CAT groups while Liu, et al., (2021) and Gay, *et al.,* (2017) assessed ARR in patients who underwent CAT treatment only. All studies: Toyokawa, *et al.,* (2021); Liu, *et al.,* (2021); Li yuan, *et al.,*(2020); Jianru,*et al.,* (2018) and Jyotirmay, *et al.,* (2021) assessed ARR occurrence on permanent upper and lower anterior teeth except Gay, *et al.,* (2017) whose study assessed ARR in upper/lower anterior teeth, canines, upper first premolars and molars. Toyokawa, *et al.,* (2021) and Gay, *et al.,* (2017) evaluated ARR in Class I malocclusion, Jianru, *et al.,* (2018) in Class I, II and III; Li yuan,*et al.,* (2020) in Class II and III and Liu *et al.,* (2021) in Class II malocclusion. ARR was assessed in non-extraction-based orthodontic treatment in the studies by Toyokawa, *et al.,* (2021); Gay, *et al.,* (2018), extraction and non-extraction-based treatment in Li yuan, *et al.,* (2020); Jyotirmay, *et al.,* (2021) and extraction-based treatment only by Li et al., (2020).

The studies assessed ARR in a total of 3,312 teeth and the sample size varied from 320; The larger the size, the more representative it is of the population and the lesser the margin for error in outcome [19,20,24]. Gay, *et al* (2017) had the largest sample size, but assessed ARR in patients treated with CAT and baseline Class I malocclusion only. Toyokawa, *et al.,* (2021) arrived at their sample size by screening participants from school/social media, took into account the mean standard deviation of a previous study on ARR in orthodontic patients and considered a significance level of 5% and power of 80% [25]. Similarly, Liu *et al.,* (2021) and Li, *et al.,* (2020) obtained their sample size from patients attending the department of orthodontics for treatment based on an estimate of ARR variability from previous studies with α set at 5%, β at 20%, effect size of 0.8; Jianru, *et al.,* (2018) and Jyotirmay, *et al.,* (2021) obtained their sample size from patients attending the hospital department of orthodontics and Gay, *et al.,* (2017) from private patients attending between December 2014 and December 2015 [26,27]. The method of determining sample size based on ARR values of previous studies and from specific groups of patients may not have reflected the actual ARR occurrence in the general population, thus introducing potential bias in the studies design.

To explore the validity of the studies, the Rob2 Cochrane risk of bias tool was used [18]. Clinicians were blinded in all the retrospective cohort studies, however, this was not possible in the randomised control trial by Toyokawa, *et al.,* (2021) and the prospective study by Gay, *et al.,* (2017) due to the patients being in active treatment, although, this may not have made a significant difference to the study outcome. However, there was blinding of personnel/investigators involved in outcome analysis in all studies with good reliability based on intra and inter-examiner correlation coefficients (ICC) /Bland-Altman analysis values obtained.

In all studies except Toyokawa, *et al.,* (2021), there was insufficient information on how participants were allocated into their study group (allocation concealment). This poses little risk to the outcome when compared with randomization of participants which ensures comparability, eliminates selection bias and potential confounding variables from influencing the outcome. There was appropriate randomisation of all participants except in Jyotirmay, et al., (2021) where there was mention of randomisation of patients, but no information on how it was achieved; Gay, *et al.,* (2017); Li, et al., (2020) and Liu, et al., (2021), provided sufficient information on how consecutive patients were recruited (after a four week interval), Jianru, et al., (2018) after ten day interval and Toyokawa, et al., (2021) used parallel randomisation in which prospectively recruited patients were randomised into two groups with no changes in the method after the trial commenced. While this is the most commonly used method of randomisation, it has the limitation of introducing large variance due to a loose connection to the control arm of the study. Toyokawa, et al., (2021) had the lowest bias by eliminating almost all Cochrane identified sources of bias from its design, earning the status of the highest quality study of all the studies (Table 4). All reviewed studies ensured similar baseline characteristics between groups and did not differentiate participants by age or gender, although previous studies have concluded that age or gender are not considered potential confounding factors [27,28]. Toyokawa, et al., (2021) assessed ARR at six months after the start of treatment, Liu, et al., (2021) for a mean treatment duration of twenty-one months; Gay, et al., (2017) for fourteen months, Li, et al., (2020) for twenty-two months and twenty-four months for FA and CAT respectively; Jianru, et al., (2018) for twenty months and twenty-two months for FA and CAT respectively; and Jyotirmay, et al., (2021) for thirty months. Jyotirmay, et al., (2021), concluded that the high ARR value obtained may be as a result of a longer duration of treatment; a conclusion supported by Pastro, et al., (2018); Baumrind, et al., (1996) and Apajalahti and Peltola, (2007) who studied factors associated with ARR after orthodontic treatment [29]. In contrast, Liu, et al, (2021) concluded that treatment duration was not an independent risk factor for ARR, a conclusion supported by Artun, et al., (2009) [30]. Liu, et al, (2021) attributed high AAR values to the participants' degree of baseline Class II malocclusion. This variable was highlighted by Aman, et al., (2018), in which ARR was found to be less in baseline Class I malocclusions compared to Class II malocclusion cases. Liu, et al., (2021) found higher ARR in extraction-based CAT orthodontic treatment compared to non-extraction which has been supported by Pastro, et al., (2018); and Artun, et al., (2009). These studies attributed this to the possibly greater tooth movement needed for closing extraction spaces and overjet reduction. Both variables are reflected in the study by Gay, et al (2017) with lower ARR values obtained in patients with Class I malocclusions who had non-extraction- based CAT orthodontic treatment. Certain types of tooth movement and the degree of movement were found to have an effect on the ARR. Liu et al, (2021), found apical intrusion and extrusion displacement were risk factors for ARR. This agreed with the findings of Chan and Liu, (2018) and Rudolph, et al., (2001) on a finite element model of apical force distribution from orthodontic tooth movement [31]. Toyokawa, et al., (2021) identified differences in biomechanics between FA and CAT appliances in relation to the type/location of force applied and moment generated as a possible reason for the very similar ARR values (0.52 −0.88 mm in the FA group and 0.52 −0.85 mm in the CAT group) obtained in both groups. This was supported by Sameshima and Sinclair (2001a), where torque application and intrusive tooth movement with the associated apical pressure application used at a later stage of treatment FA were found to increase the risk of ARR [32]. The reviewed studies used different methods of outcome measurements, the quality of which may influence the accuracy of the study outcome. Jyotirmay, et al., (2021); Li yuan, et al., (2020) and Liu, et al, (2021) assessed ARR with CBCT scans, whereas Toyokawa, et al., (2021) used periapical radiographs, Jianru, et al., (2018) and Gay, et al (2017) used panoramic radiographs. The amount of ARR in the studies that used the three-dimensional (CBCT scan) method for outcome measurement was less compared to studies that used two-dimensional methods (panoramic / periapical radiographs) [21,23]. This was attributed to CBCT having better diagnostic values and image quality compared to periapical radiographs [33]. Clinically, justification for CBCT scan use precludes routine prescription, in spite of its role as a better measurement tool for 3-dimensional changes (ARR) in the tooth structure compared to 2-dimensional radiograph (periapical and panoramic). Current guidelines suggest insufficient clinical justification for the routine use of CBCT scan pre- and post-orthodontic treatment for detection of ARR. Apical root resorption calculation varied among studies: Toyokawa, et al., (2021) measured ARR as the difference between the pre- and post-treatment root length whereas Liu, et al., (2021) assessed root volume loss; Gay, et al., (2017) used the relative change in root crown ratio (determined by considering the pre- and post-treatment root and crown lengths); Li, et al., (2020) calculated ARR as the difference in tooth length before and after treatment; Jianru, et al., (2018) and Jyotirmay, et al., (2021) calculated ARR as the difference in the root length before and after treatment. This lack of consistency in the ARR calculation makes comparison challenging and can affect the ability to make appropriate recommendations on ARR. Toyokawa, et al., (2021) reported a similar degree of ARR in maxillary and mandibular anterior teeth at the end of six months of treatment except in tooth #21 in which there was a statistically significant difference between the CAT and FA groups ($p=0.037$), however the overall difference between the two groups was considered by the authors to be clinically insignificant; in the study by Liu, et al., (2021) most incisors assessed showed mild to moderate root volume reduction(ARR) following treatment with CAT($p<0.001$) with a significant decrease of 11.48 ± 6.70 mm3 in mean root volume and only 0.63% had severe ARR; Gay, et al., (2017) reported all patients treated with CAT had a minimum of one tooth affected by the reduction in post-treatment root length (rRCR <100%), on average 6.38 ± 2.28 teeth per patient. The incidence of ARR reported was 41.81% of the assessed 1083 teeth, the incidence of minimal (up to 10%) ARR was 25.94%; mild (10-20%) was 12.18% and severe (>20%) was 3.69% (mostly affecting maxillary left premolars, maxillary left lateral incisors, mandibular right lateral and central incisors). This value was consistent with the results of Krieger, et al., (2013). Li, et al., (2020) found ARR severity in the CAT group (0.13 ± 0.47mm, on average) to be significantly less than FA(1.12 ± 1.34mm, on average) and this applied to every individual tooth included in the study (p<0.001); the most severely affected were maxillary canine and lateral incisors in the FA group and least affected were mandibular canines and lateral incisors in the CAT group; Jianru, et al., (2018) found an overall mean value of ARR in the CAT group of 5.13 ± 2.81 %, significantly less than the FA group of 6.97 ± 3.67 %. Similarly, the maxillary central incisor/lateral incisors and mandibular central incisor/lateral incisors of the CAT group had less ARR than the FA group (P<0.001); Jyotirmay et al., (2021) observed more ARR in patients treated with FA (mean value of 1.51 ± 1.34mm) compared to CAT (1.12 ± 1.34mm) (P<0.001); similar results were obtained when individual teeth where considered. In the FA group the amount of ARR was greatest in maxillary central incisors, least in mandibular central incisors and in the CAT group, ARR was greatest in maxillary canines and least in mandibular incisors.

All studies showed that ARR can occur in patients who had undergone orthodontic treatment with either fixed appliances or clear aligners. The incidence/severity of ARR in the clear aligners group was statistically significantly less than that of the fixed appliance group in the studies by Jyotirmay, et al., (2021); Li, yuan, et al., (2020) and Jianru, et al., (2018), however, Toyokawa, et al., (2021) reported little or no overall difference statistically or clinically in ARR occurrence in both the fixed and clear aligner groups (Table 5). It is unclear if this finding was due to short treatment duration of this study when compared to the other studies, however previous studies have justified the detection of ARR within short treatment duration as good for early diagnosis of patients more prone genetically to developing apical root resorption during orthodontic treatment and a basis for monitoring/controlling its occurrence throughout the treatment duration [34,35]. Also, the difference observed may be related to certain types of tooth movement, such as torque application used in the later stages of fixed appliance treatment, which has been found to increase the amount of ARR [36]. Gay, et al., (2017) and Liu, et al., (2021) who both investigated ARR severity and prevalence in clear aligner groups only, reported ARR occurrence but Liu, et al., (2021) had higher prevalence values which may be due to other variables associated with the participants such as extraction & non-extraction-based treatment or a baseline Class II malocclusion as compared to Gay, et al., (2017) who chose non-extraction or baseline Class I malocclusion cases.

STUDY	Root resorption (FA)	Root resorption (CAT)	Statistical (P-value)/Clinical significance
Toyokawa *et al*., (2021),	0.52 to −0.88 mm	0.52 to −0.85 mm	Only tooth #21 showed statistically significant difference between the CAT and FA groups (*p*=0.037), but overall difference between the CAT and FA groups was clinically insignificant
Liu *et al*, (2021)		11.48 ± 6.70 mm^3	P<0.001(statistically significant) All teeth showed volume reduction due to ARR
Jyotirmay *et al.,* (2021	1.51 ± 1.34mm	1.12 ± 1.34mm	P<0.001(the severity of ARR was statistically significant less in CAT than in FA group (on average)). The ARR was statistically significant and more in all teeth treated with FA, But only in maxillary incisors and mandibular central incisors in the CAT group
Li, *et al*., (2020);	Severity:1.12 ± 1. 34mm Prevalence: 82.11%	0.13 ± 0.47 mm 56.30%	P<0.001(the severity and prevalence of ARR was statistically significant less in CAT than in FA group). Also, in individual tooth in FA group, but only in maxillary incisors and mandibular central incisors in the CAT group
Jianru *et al.*, (2018)	6.97 ± 3.67%	5.13 ± 2.81%	P<0.001(the overall ARR was statistically significant lower in the CAT than the FA group) –Similarly maxillary and mandibular central/lateral incisor in CAT had less ARR than the FA group
Gay*, et al* (2017)		6.38 ± 2.28 teeth per patient (on average)	All patients had minimal of one tooth show sign of ARR. 25.94% showed reduction of up to 10%(minimal), 12.18% show reduction of between 10%-20%(mild) but only 3.69% of treated tooth show >20% reduction of pre-treatment root length

Table 5: Comparison of Apical Root Resorption in Reviewed Studies

Conclusions and Implications

Based on the reviewed studies, it can be concluded that ARR can occur in both FA or CAT treated orthodontic patients and mostly affects anterior teeth, but the severity varies. The RCT by Toyokawa, et al., (2021) found ARR occurrence is similar in CAT and FA groups, however, the study was undertaken within a short treatment duration and thus has limited data on outcome. Li yuan, et al., (2020); Jianru, et al., (2018) and Jyotirmay, et al., (2021); retrospective cohort studies found ARR occurrence to be less with CAT compared to FAs, however, these had weak study methods. In addition, their findings are based on patients with different baseline malocclusion/method of outcome measurement limiting comparability and potentially influencing outcome data. Although the majority of the reviewed studies concluded that ARR was less in CAT than FA treated groups, but the above identified reasons make this inconclusive.

Due to this limited evidence, it is difficult to make appropriate recommendations applicable to everyday clinical practice, and therefore clinicians should take into consideration other variables that could influence the risk of ARR occurrence such as genetic predisposition, treatment duration, force application (types and location), types of tooth movement, initial malocclusion and extraction/non-extraction-based treatment, when making decisions on appliance type and gaining patient consent for orthodontic treatment at the treatment planning stage.

The current evidence has a number of limitations including the lack of robust prospective studies on ARR, different methods of outcome measurement and calculation, different baseline malocclusions, the evaluation of ARR in only one treatment modality and short treatment duration which may influence the validity of the study outcomes [19,20,24]. A meta-analysis cannot be performed due to heterogeneous outcome measurements [37-42].

Future Research

In view of the deficiencies identified in the current research, more studies are recommended including the following design features:

- An RCT with Inclusion/exclusion criteria for patient recruitment clearly defined
- Power calculation for selection of an appropriate sample size
- Allocation concealment and randomisation of participants into two intervention groups (FA & CAT involving different types of malocclusions) with a control group. This would help to balance known/unknown confounding factors and reduce their impact on the outcome.
- Blinding of personnel and data analysts
- Standardised method of outcome measurements
- 18-24months duration of treatment reflecting the average period of orthodontic treatment
- Pre-stated data analysis strategy and statistical plan
- Evaluation of outcome on intention-to treat basis

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