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Literature Review

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ABSTRACT

AIM: This study compared the effectiveness of fixed appliances (FA) and clear aligner treatment (CAT) in the management of malocclusion, with a particular focus on crowding, pain, treatment duration, and root resorption.

METHODS: A systematic review was conducted using PubMed and Google Scholar to identify studies published in English between 2003 and 2021. Data were extracted on malocclusion correction, root resorption, treatment duration, pain perception, and quality of life. The included studies were synthesised to compare outcomes between treatment with FA and CAT.

RESULTS: Twenty-three studies were included. Treatment with FA was found to be more effective for the correction of malocclusion, proclination, and proximal contact; however, both modalities were associated with mild root resorption of the maxillary and mandibular anterior teeth, with CAT showing less resorption. CAT was also associated with shorter treatment duration, lower pain perception, and better quality of life.

CONCLUSION: Both modalities were effective in the treatment of malocclusion; however, CAT appeared to offer particular advantages in cases of mild crowding, including shorter treatment duration, improved quality of life, and reduced pain, whereas FA were more suitable for mild to severe cases. Both modalities resulted in mild root resorption of the anterior teeth, and treatment selection should therefore be individualised.

Keywords: Clear aligners, Comparison, Orthodontics, Treatment outcomes, Fixed appliances

1. Introduction

Fixed appliances (FA) have been regarded as the gold standard of orthodontic treatment for more than a century and remain widely used worldwide. However, in recent years, patients have become increasingly concerned with aesthetics and comfort. As many patients now seek alternatives to treatment with FA for these reasons, lingual appliances and clear aligners (CA) have emerged as important treatment options.

In 1946, Kesling first introduced the concept of CA. Over the past two decades, CA have gained considerable popularity, particularly in Europe and the United States. More recently, they have also become increasingly recognised in Asia and South-East Asia. In the past, many Asian patients preferred treatment with FA because of financial constraints, traditional values, and fashion trends. Today, however, CA are becoming more popular, as some patients place greater emphasis on comfort and aesthetics. As removable appliances, CA may facilitate better oral hygiene. Consequently, many patients regard clear aligner treatment (CAT) as a more attractive orthodontic option and as a means of improving quality of life. In addition, some studies have reported that CAT is associated with better periodontal health and lower pain perception than FA, with patients describing the treatment as more comfortable and less painful. Nevertheless, these findings remain controversial and require further investigation.

Root resorption may occur as a result of multiple factors, including trauma, genetic predisposition, and orthodontic treatment. In the orthodontic context, factors such as appliance type, patient age, extraction versus non-extraction treatment, the magnitude of force applied for tooth movement, treatment duration, and the distance of tooth movement may contribute to apical root resorption. Moreover, the maxillary and mandibular anterior teeth are the sites most commonly affected by orthodontically induced external root resorption. Therefore, careful assessment of root resorption is essential in patients undergoing orthodontic treatment. Some studies have suggested that CAT may reduce root resorption compared with other orthodontic modalities, whereas others have reported greater root resorption with CAT than with FA.

Several studies have also suggested that CAT can be effective in the correction of malocclusion and dental misalignment. Initially, CAT was considered suitable primarily for the management of mild crowding and spacing. However, a growing body of evidence now suggests that CAT has improved and, in certain cases, may be as effective as FA.

Despite these advances, the effectiveness and predictability of CAT remain open to debate, and further evidence is needed to clarify its benefits and limitations. Therefore, the aim of this study is to evaluate and compare the effectiveness and limitations of CAT and FA in the treatment of malocclusion in patients aged 20 to 40 years, with particular reference to outcomes such as crowding, occlusion, pain perception, external root resorption, and treatment duration.

2. Methods

The PICO framework was defined as follows: the population comprised patients aged 24 to 40 years with mild dental crowding or malocclusion undergoing non-extraction orthodontic treatment; the intervention was clear aligner treatment (CAT) using Invisalign; the comparison was treatment with fixed appliances (FA), specifically buccal FA using MBT or Roth prescriptions; and the outcomes included treatment effectiveness (occlusion, contacts, alignment, arch width, derotation, and inclination), external root resorption, pain, and treatment duration.

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An electronic search, restricted to studies published in English, was conducted using PubMed and Google Scholar for the period from 2003 to 2021. The reference lists of included studies and relevant reviews were also screened to identify additional eligible studies. The PubMed search strategy included the following terms: ((clear aligner)) AND (((fixed appliances) OR (fixed appliance)) AND (orthod*)), sorted by Most Recent, and ((clear aligner) OR (Invisalign)) AND (((fixed appliances) OR (fixed appliance)) AND (orthod*)), also sorted by Most Recent. The Google Scholar search strategy included the following terms: conventional (buccal) fixed orthodontic appliance, clear aligner (Invisalign), conventional fixed appliance and clear aligner, conventional fixed appliance compare clear aligner AND effectiveness, and (conventional fixed appliance AND clear aligner) AND (effective OR malocclusion OR external root resorption OR pain).

The inclusion criteria were as follows: studies published in English between 2003 and 2021; studies comparing CA with FA, including studies that additionally evaluated other appliance types, provided that both CA and FA were included; studies involving human clinical orthodontic treatment in the permanent dentition; and randomised or non-randomised clinical trials, as well as prospective or retrospective cohort studies.

The exclusion criteria were non-human studies, in vitro studies, case reports, and letters to the editor.

Titles and abstracts were screened initially, followed by full-text assessment. A total of 230 articles compared FA with CA in relation to malaligned teeth, malocclusion, treatment effectiveness, root resorption, pain, and treatment duration. Of these, nine focused on malocclusion, ten reported treatment outcomes related to external root resorption, and five examined pain perception.

2.1. Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyse the textual content of the included studies. It should be noted that, given the narrative nature of this study, neither regression analysis nor meta-analysis was considered appropriate for the analytical framework.

3. Results

3.1. Study characteristics

Twenty-three studies reported information on the effectiveness of orthodontic treatment with clear aligners (CA) and fixed appliances (FA), as shown in **Supplemental Table S1**. The earliest study was published in 2005, whereas the most recent was published in 2021. With regard to study design, 13 studies were retrospective comparative clinical studies, four were prospective comparative clinical studies, four were randomised controlled trials, and one was a cross-sectional study. A total of 793 patients were treated with CA, while a further 740 patients were treated with FA. The gender distribution was balanced between the two groups across the included studies, except in Sfondrini et al. (2018), which did not report patient sex. The mean age of the patients ranged from 13.42 to 33.6 years. Fourteen studies included non-extraction patients, two included extraction patients, and the remaining studies did not report extraction status. Ten studies included patients with Class I malocclusion, whereas the remainder did not specify the classification of malocclusion. The mean treatment duration ranged from 10.2 to 22.08 months for CA and from 11.8 to 23.31 months for FA. Seventeen studies compared the effectiveness of CA and FA, two reported results for CA only, and

four reported results for FA only. Nine studies assessed the effectiveness of malocclusion treatment, 10 reported root resorption after treatment, and five evaluated pain perception during treatment.

3.2. Effectiveness

According to the Phase III examination criteria of the American Board of Orthodontics, two studies used the Objective Grading System (OGS) to evaluate and compare treatment effectiveness between CA and FA, as shown in **Table 1**. The OGS assesses marginal ridges, buccolingual inclination, tooth alignment, occlusal relationships, overjet, root angulation, and occlusal and interproximal contacts. Both Djeu et al. (2005) and Kuncio et al. (2007) used the OGS to assess alignment, and both found that FA achieved better OGS scores than CA. One included study, Djeu et al. (2005), also found significantly greater loss of OGS points in the CA group ($P < 0.0001$), whereas Kuncio et al. (2007) found no statistically significant difference between the two groups ($P = 0.1208$). Moreover, Djeu et al. (2005) showed that 10 CA cases (20.80%) scored fewer than 30 OGS points and therefore received a passing score in the ABO Phase III examination, whereas 23 FA cases (47.90%) achieved a passing OGS score. These findings suggest that patients treated with CA may have a higher risk of relapse than those treated with FA. Overall, these studies indicate that CA were less effective than FA in the treatment of malocclusion.

Table 1. Effectiveness of CA and FA assessed with the OGS grading system.

AUTHOR (YEAR)	MEASUREMENT	ALIGNER	BRACES	P VALUE
Djeu (2005)	OGS score	-45.35 ± 15.56	-32.21 ± 11.73	<0.0001
Djeu (2005)	N of ≤ 30 OGS score	10 (20.8%)	23 (47.9%)	0.0052
Kuncio (2007)	OGS score	-0.73 ± 5.58	2.55 ± 7.30	0.1208

3.2.1. Peer Assessment Rating index

Table 2 shows that three included studies used the Peer Assessment Rating (PAR) index to evaluate and compare the effectiveness of CA and FA. The PAR index assesses eight components, including the alignment of the maxillary and mandibular anterior teeth, anteroposterior discrepancy, transverse discrepancy, vertical discrepancy, overjet, overbite, and midline. The results of Gu et al. (2017) and Yi et al. (2018) showed that CA had a lower weighted PAR score reduction than FA. However, no statistically significant difference was found between the two groups. Richmond et al. (Year) suggested that a reduction of 22 PAR points represented a great improvement. Gu et al. (2017) found that CA had a statistically significantly lower proportion of cases classified as showing great improvement (22.9%) than FA (45.8%; $P < 0.015$). Lanteri et al. (2018) similarly reported that CA resulted in 42% of cases being classified as showing great improvement and an 80.9% improvement in the weighted PAR score, whereas FA resulted in 46% of cases being classified as showing great improvement and a 91.0% improvement in the weighted PAR score. These studies therefore indicate that the FA group had a statistically significantly higher rate of great improvement than the CA group. Taken together, these findings suggest that CA were less effective than FA in

the correction of tooth alignment, anteroposterior and transverse discrepancies, overjet, overbite, and midline discrepancies.

Table 2. Effectiveness of CA and FA assessed with the PAR score.

AUTHOR (YEAR)	MEASUREMENT	ALIGNER	BRACES	P VALUE
Gu (2017)	Weighted PAR reduction	16.73 ± 6.78	20.1±8.06	0.457
Gu (2017)	N of great improvement	11 (22.9%)	22 (45.8%)	0.015
Lanteri (2018)	% of PAR score improvement	80.9%	91.0%	< 0.05
Lanteri (2018)	% of great improvement	42%	46%	< 0.05
Yi (2018)	Weighted PAR reduction	16.57 ± 5.76	19.03± 7.68	0.116

3.2.2. Proclination

Four studies compared the effectiveness of CA and FA in relation to proclination (**Table 3**). All four studies indicated that FA produced better outcomes than CA. Pavoni et al. (2011) found that FA produced statistically significantly different outcomes in transverse dentoalveolar width and maxillary arch perimeter during treatment compared with CA. In addition, two studies evaluated the effectiveness of CA and FA in relation to proclination of the mandibular anterior teeth. Grunheid et al. (2016) showed that patients treated with FA had significantly greater decreases in mandibular canine proclination than those treated with CA. Hennessy et al. (2016) also found that FA increased mandibular incisor proclination during alignment more than CA, although no statistically significant difference was observed between the two groups. Sfondrini et al. (2018), using different parameters including 11∧ SnaSnp, 11∧ Ocl, and $I + TVL$ to assess incisor position, likewise found greater incisal position values in the FA group, although again the difference was not statistically significant.

3.2.3. Alignment

According to **Table 4**, five studies reported outcomes relating to alignment. OGS and PAR scores were also used to assess tooth alignment; therefore, these studies could be used to compare the effectiveness of alignment between CA and FA. All five studies showed that FA were more effective than CA in achieving alignment.

Three studies showed statistically significant differences between CA and FA, whereas two found no statistically significant differences between the groups. Kuncio et al. (2007) reported the difference between the CA and FA groups with regard to changes in total alignment from pre-treatment to post-treatment ($P = 0.340$). The total alignment score was 2.91 ± 1.64 for CA and 1.36 ± 1.21 for FA. No statistically significant differences were found in PAR score reduction or in the more detailed analysis of the alignment category of arch perimeter, defined as the sum of the segments between contact points from the mesial surface of the first permanent molar to the mesial surface of the contralateral first permanent molar. However, statistically significant differences

Table 3. Effectiveness of CA and FA to reduce incisor proclination.

AUTHOR (YEAR)	MEASUREMENT	ALIGNER	BRACES	P VALUE
Pavoni (2011)	Mx ICW (cusp), T0–T1 change	0.5 ± 1.1 mm	3.2 ± 2.3 mm	< .001
Pavoni (2011)	Mx IPW1 (fossa) change	0.1 ± 0.5 mm	3.4 ± 2.0 mm	< .001
Pavoni (2011)	Mx IPW2 (fossa) change	0.5 ± 0.5 mm	2.5 ± 2.2 mm	< .001
Pavoni (2011)	Mx IMW (fossa) change	0.5 ± 0.5 mm	0.9 ± 2.5 mm	.479
Pavoni (2011)	Mx AD change	0.0 ± 1.2 mm	1.9 ± 11.4 mm	.463
Pavoni (2011)	Mx AP change	−0.1 ± 1.6 mm	1.3 ± 2.2 mm	.034
Grunheid (2016)	BL inclination of L C	0.7 ± 2.5 mm	21.9 ± 5.1 mm	< .001
Grunheid (2016)	Intercanine distance	0.7 ± 1.5 mm	20.1 ± 2.4 mm	< .001
Hennessy (2016)	Md Inc proclination inc.	3.4 ± 3.2°	5.3 ± 4.3°	.14
Sfondrini (2018)	11∧SNASNP	5.1 ± 3.2 mm	6.1 ± 3.9 mm	> .05
Sfondrini (2018)	11∧OCL	4.60 ± 3.46 mm	6.88 ± 4.28 mm	> .05
Sfondrini (2018)	I + TVL	1.47 ± 0.57 mm	1.56 ± 0.47 mm	> .05

Table 4. Effectiveness of alignement in CA and FA treatment.

AUTHOR (YEAR)	MEASUREMENT	ALIGNER OUTCOME	BRACES OUTCOME	P VALUE
Djeu (2005)	OGS score	-45.35 ± 15.56	-32.21 ± 11.73	<0.0001
Kuncio (2007)	Total alignment	-2.91 ± 1.64	-1.36 ± 1.21	0.340
Gu (2017)	Weighted PAR score reduction	16.73 ± 6.78	20.1 ± 8.06	0.457
Yi (2018)	Weighted PAR score reduction	16.57 ± 5.76	19.03 ± 7.68	0.116
Lanteri (2018)	% of improved PAR score	80.9%	91.0%	< 0.05

were observed in OGS score and total alignment between CA and FA. These findings indicate that patients treated with FA achieved better alignment outcomes than those treated with CA.

3.3. External root resorption

Ten studies investigating root resorption used different measurement methods and examined different anatomical sites. Four studies used CBCT (**Table 5**), four used panoramic radiographs, and two used periapical radiographic techniques for analysis (**Table 6**).

Six studies reported root resorption in different teeth. Four comparative studies found that CA were associated with less severe root resorption across different teeth than FA. However, two non-comparative studies showed statistically significant root resorption of the maxillary central incisors, maxillary lateral incisors, mandibular central incisors, and mandibular lateral incisors following treatment with FA.

In addition, three included studies showed that CA resulted in less overall root resorption than FA, with statistically significant differences between the groups. Across all studies, root resorption of the anterior teeth was identified in every case. The average extent of root resorption associated with CA was approximately 0.1–5 mm in at least two teeth per case and was generally classified as mild, whereas that associated with FA was approximately 0.23–6 mm in at least two teeth per case and was also generally classified as mild.

According to **Table 5** and **6**, six studies evaluated root resorption in individual teeth. Four included studies assessed the maxillary central incisors, maxillary lateral incisors, mandibular central incisors, and mandibular lateral incisors, whereas Li et al. (2020) evaluated all maxillary and mandibular anterior teeth. All evaluated teeth showed evidence of root resorption following treatment with either CA or FA. Overall, lower levels of root resorption were reported with CA than with FA in all teeth examined.

Four studies assessed root resorption using RR scores. Krieger et al. (2013) and Gay et al. (2017) used the rRCR score to evaluate the percentage of root resorption, Jyotirmay et al. (2021) assessed root resorption using the ARR score, and Agarwal et al. (2016) used a four-grade ordinal scale proposed by Scott-McNab (Year). These scoring systems were used to evaluate the severity of root resorption and could therefore indicate differences in root resorption between CA and FA (**Table 7**).

Jyotirmay et al. (2021) compared root resorption between CA (maxillary lateral and central incisors) and FA (maxillary and mandibular anterior teeth) using Sharpe's method for ARR ($P < 0.001$). They found that CA were associated with statistically significantly lower root resorption than FA. In the CA group, 54.86% of teeth fell into the first severity category, with no teeth in the second or third severity categories. In contrast, the FA group showed root resorption across all severity categories, with 62.32% of teeth falling into the first severity category.

However, two non-comparative studies, Gay et al. (2017) and Krieger et al. (2013), used panoramic radiographs to evaluate root resorption associated with CA and interpreted the findings using the rRCR score. Gay et al. (2017) found that a reduction of $> 0\%$ up to 10% was present in 25.94% of teeth, a reduction of $>$ 10–20% in 12.18%, and a marked reduction of $> 20\%$ in 3.96% of teeth. Similarly, Krieger et al. (2013) found that, on average, 7.36 teeth were affected. In total, 54% of patients had no measurable root resorption. A reduction of $> 0\%$ up to 10% was found in 27.75% of teeth, a reduction of $>$ 10–20% in 11.94%, and a marked reduction of $> 20\%$ in 6.31% of teeth. These studies indicate that at least two teeth with root resorption, with an average reduction

Table 5. CBCT comparison of root resorption: CA vs FA.

AUTHOR (YEAR)	MEASUREMENT	TEETH	RR ALIGNER	RR BRACES	P VALUE	T ALIGNER	T BRACES
Eissa (2018)	CBCT	Max Rt Lateral	0.364 ± 0.323	0.964 ± 0.516	0.003	15.14 ± 1.94	16.22 ± 2.75
Eissa (2018)	CBCT	Max Rt Central	0.505 ± 0.428	1.136 ± 0.638	0.012	15.14 ± 1.94	16.22 ± 2.75
Eissa (2018)	CBCT	Max Lt Central	0.455 ± 0.364	0.973 ± 0.687	0.089	15.14 ± 1.94	16.22 ± 2.75
Eissa (2018)	CBCT	Max Lt Lateral	0.436 ± 0.298	1.091 ± 0.858	0.025	15.14 ± 1.94	16.22 ± 2.75
Eissa (2018)	CBCT	Overall	0.44 ± 0.35	1.04 ± 0.67	< 0.05	15.14 ± 1.94	16.22 ± 2.75
Li (2020)	CBCT	Max Canine	69.35%	84.62%	0.041	21.54 ± 5.55	23.31 ± 6.25
Li (2020)	CBCT	Max Lateral	69.35%	88.52%	0.009	21.54 ± 5.55	23.31 ± 6.25
Li (2020)	CBCT	Max Central	45.00%	80.00%	0.001	21.54 ± 5.55	23.31 ± 6.25
Li (2020)	CBCT	Mand Central	60.00%	78.69%	0.023	21.54 ± 5.55	23.31 ± 6.25
Li (2020)	CBCT	Mand Lateral	53.85%	88.33%	0.001	21.54 ± 5.55	23.31 ± 6.25
Li (2020)	CBCT	Mand Canine	35.38%	72.58%	0.001	21.54 ± 5.55	23.31 ± 6.25
Li (2020)	CBCT	Overall	56.30%	82.11%	0.001	21.54 ± 5.55	23.31 ± 6.25

Table 6. Root resorption with braces by tooth region.

AUTHOR (YEAR)	MEASUREMENT	TEETH	RR BRACES	P-VALUE
Leite (2012)	CBCT	Max Lateral	0.43	0.001
Leite (2012)	CBCT	Max Central	0.34	0.001
Leite (2012)	CBCT	Mand Central	0.39	0.031
Leite (2012)	CBCT	Mand Lateral	0.23	0.007
Chen (2015)	Periapical	Max Lateral	0.5	< 0.05
Chen (2015)	Periapical	Max Central	0.3	< 0.05
Chen (2015)	Periapical	Mand Central	0.4	< 0.05
Chen (2015)	Periapical	Mand Lateral	0.3	< 0.05

Table 7. Scoring system related severity of root resorption using CA and FA.

AUTHOR (YEAR)	MEASUREMENT	SEVERITY	ALIGNER OUTCOME (%)	BRACES OUTCOME (%)	P VALUE
Jyotirmay (2021)	CBCT (Sharpe)	Zero	45.13	19.45	-
Jyotirmay (2021)	CBCT (Sharpe)	One	54.86	62.32	-
Jyotirmay (2021)	CBCT (Sharpe)	Two	0	17.70	-
Jyotirmay (2021)	CBCT (Sharpe)	Three	0	-	-
Jyotirmay (2021)	CBCT (Sharpe)	Overall	1.12 ± 1.34	1.51 ± 1.34	-
Krieger (2013)	Panoramic (rRCR score)	rRCR < 80	6.31	-	-
Krieger (2013)	Panoramic (rRCR score)	80 ≤ rRCR < 90	11.94	-	-
Krieger (2013)	Panoramic (rRCR score)	90 ≤ rRCR < 100	27.75	-	-
Krieger (2013)	Panoramic (rRCR score)	rRCR ≥ 100	54	-	-
Gay (2017)	Panoramic (rRCR score)	rRCR < 80	3.69	-	-
Gay (2017)	Panoramic (rRCR score)	80 ≤ rRCR < 90	12.18	-	-
Gay (2017)	Panoramic (rRCR score)	90 ≤ rRCR < 100	25.94	-	-
Gay (2017)	Panoramic (rRCR score)	rRCR ≥ 100	58.12	-	-
Agarwal (2016)	Panoramic (ScottMcNab)	No EARR	-	53.2	-
Agarwal (2016)	Panoramic (ScottMcNab)	Mild	-	44.4	-
Agarwal (2016)	Panoramic (ScottMcNab)	Moderate	-	2.4	-
Agarwal (2016)	Panoramic (ScottMcNab)	Severe	-	0	-
Agarwal (2016)	Panoramic (ScottMcNab)	Extraction	-	43.13	0.001
Agarwal (2016)	Panoramic (ScottMcNab)	Non extraction	-	2.45	0.294

of $< 10\%$, may be found in patients treated with CA. Overall, the included studies suggest that mild root resorption may occur during treatment with CA.

Agarwal et al. (2016) reported the effects of FA on root resorption. They found that 53.2% of patients showed no radiographic evidence of EARR after treatment, 44.4% showed mild EARR, 2.4% showed moderate EARR, and none showed severe EARR. Moreover, they found that extraction cases had statistically significantly greater root resorption than non-extraction cases. These findings indicate that FA were also associated with mild root resorption affecting at least two teeth in each case.

Both ARR and rRCR scores were used to evaluate root resorption. Although each study used a different scoring system, both were able to indicate the severity of root resorption.

3.4. Pain

Five studies assessed pain perception (**Table 8**), using different instruments to collect data, including quality-of-life questionnaires and discomfort visual analogue scale (VAS) scores. The results showed that patients treated with CA and FA experienced the highest pain levels on day 1, with pain decreasing significantly by the end of the first week or by day 7.

Table 8. Outcomes of pain perception using CA and FA.

AUTHOR (YEAR)	MEASUREMENT	DAY	ALIGNER	BRACES	P VALUE
Shalish (2012)	HRQoL questionnaire	Day 1	6.08 ± 2.84	4.50 ± 2.50	NS
Shalish (2012)	HRQoL questionnaire	Day 7	2.58 ± 2.41	2.06 ± 1.66	NS
White (2017)	Discomfort VAS	Day 1	5.05	16.87	0.045
White (2017)	Discomfort VAS	Day 7	3.19	13.80	0.008
Miller (2007)	Discomfort VAS	Day 1	42 %	67 %	0.06
Miller (2007)	Discomfort VAS	Day 7	3 %	11 %	0.32
Almasoud (2018)	VAS score	Day 1	1.38 ± 2.69	6.0 ± 3.41	0.001
Almasoud (2018)	VAS score	Day 7	0.41 ± 1.6	2.69 ± 3.09	0.001
Almasoud (2018)	VAS score	Day 1	1.38 ± 2.69	6.0 ± 3.41	0.001*
Almasoud (2018)	VAS score	Day 7	0.41 ± 1.6	2.69 ± 3.09	0.001*

Note:

All included studies showed that both CA and FA were associated with the highest pain perception on the first day, followed by improvement by day 7. Only Shalish et al. (2012) reported higher pain perception with CA than with FA, although the difference between the two groups was not statistically significant. By contrast, the other four studies concluded that CA were associated with lower pain perception than FA on both day 1 and day 7.

Four included studies showed that patients treated with CA experienced less pain and discomfort than those treated with FA on the first day and during the first week. In contrast, Shalish et al. (2012) reported that Invisalign patients experienced higher pain levels on the first day and higher mean pain levels than patients treated with buccal appliances after insertion (severe pain with Invisalign = 38.1%, FA = 9–10%, P value = NS). Although the results of Shalish et al. (2012) suggested that CA were associated with higher pain levels than FA, no significant difference was found between the two groups in either average or severe pain on the first day. These findings indicate that patients treated with either CA or FA experienced the highest pain on day 1, which subsequently decreased over the course of the week. However, patients treated with CA generally reported less pain and discomfort in daily life during the first week of orthodontic treatment than those treated with FA.

3.5. Quality of life

Two studies used quality-of-life questionnaires to evaluate quality of life (**Table 9**). Shalish et al. (2012) found that patients treated with CA had statistically significantly lower levels of oral dysfunction, disturbances in eating, and oral symptoms than those treated with FA. Moreover, Azaripour et al. (2015) showed that patients treated with CA had significantly lower impairment of general well-being and brushed their teeth more frequently than those treated with FA, whereas no

significant difference in eating habits was observed between the two groups. Patients treated with CA were also more likely to state that they would choose the same treatment again than patients treated with FA. These findings suggest that patients treated with CA had a better quality of life than those treated with FA.

Table 9. Outcomes of quality of life using CA and FA.

AUTHOR (YEAR)	MEASUREMENT	DYSFUNCTION	ALIGNER	BRACES	P VALUE
Shalish (2012)	HRQoL questionnaire	Oral dysfunction	1.10 ± 0.16	1.27 ± 0.48	0.005
Shalish (2012)	HRQoL questionnaire	Disturbances in eating	1.23 ± 0.64	2.01 ± 0.13	<0.001
Azaripour (2015)	HRQoL questionnaire	Impairment of general well being	6%	36%	0.001
Azaripour (2015)	HRQoL questionnaire	Change of eating habits	50%	70%	0.066
Azaripour (2015)	HRQoL questionnaire	Frequency of tooth brushing	52%	84%	0.001
Azaripour (2015)	HRQoL questionnaire	Several treatments	98%	78%	0.004

3.6. Treatment duration

Twelve studies compared treatment duration between CA and FA. The duration of treatment with CA ranged from approximately 13.35 to 22.23 months, whereas treatment with FA ranged from approximately 12.9 to 28.1 months (**Table 10**).

Eleven studies found that the CA group had a shorter treatment duration than the FA group, and four studies reported statistically significant differences between the two groups. The only study by Yi et al. (2018) found that CA had a longer treatment duration than FA, although the difference was not statistically significant (CA $= 22.08 \pm 4.51$, FA $= 20.83 \pm 5.29$). Two studies reported treatment duration for Invisalign or CA only: Krieger et al. (2013) reported 19.8 months, and Gay et al. (2017) reported 14 months. One study, Chen et al. (2015), reported only the treatment duration for FA (20.34 ± 3.40 months). Overall, these findings indicate that patients treated with CA tended to have a shorter treatment duration than those treated with FA.

4. Discussion

This study compared clear aligner treatment (CAT) and treatment with fixed appliances (FA) with respect to aesthetics, treatment outcomes, and patient comfort. Overall, the findings suggest that FA are more effective than CAT in the treatment of malocclusion. Patients treated with FA had a statistically significantly higher rate of achieving great improvement than those treated with CAT ($p < 0.05$). Moreover, comparisons based on OGS scores indicated that FA produced better malocclusion outcomes than CAT.

CAT may be appropriate for the treatment of mild malocclusion, whereas FA can be used in both mild and more severe cases. Both CA and FA may also contribute to the maintenance of tooth alignment and the prevention of relapse after treatment. This is consistent with Yi et al. (2018), who suggested that CA have limitations in the treatment of malocclusion. Similarly, Lombardo et

Table 10. Treatment duration using CA and FA.

AUTHOR (YEAR)	ALIGNER (MONTH)	BRACES (MONTH)	P-VALUE
Djeu (2005)	16.8	20.4	0.0138
Kuncio (2007)	20.9 ± 10	28.1 ± 9.2	0.0941
Pavoni (2011)	18 ± 2	18 ± 3	>0.05
Grunheid (2016)	13.4 ± 6.8	20.2 ± 5.3	< 0.05
Hennessy (2016)	10.2	11.3	> 0.05
Gu (2017)	13.35 ± 8.63	19.08 ± 5.92	0.004
Lanteri (2018)	14	19	< 0.05
Yi (2018)	22.08 ± 4.51	20.83 ± 5.29	0.259
Eissa (2018)	15.14 ± 1.94	16.22 ± 2.75	0.48
Krieger (2013)	19.8	-	-
Gay (2017)	14	-	-
Chen (2015)	-	20.34 ± 3.40	> 0.05
Agarwal (2016)	-	19.2 – 27.6	-
Li et al. (2020)	21.54 ± 5.55	23.31 ± 6.25	-
Cristina (2016)	6	6	-
Jyotirmay (2021)	22.23 ± 7.34	22.45 ± 6.54	-
Azaripour (2015)	12.6 ± 7.4	12.9 ± 7.2	0.82

al. (2017) reported that CA are suitable for mild to moderate cases, whereas FA are appropriate for mild to severe crowding.

4.1. Crowding, occlusion, proximal contact and tooth inclination

The included studies indicated that patients treated with FA achieved better treatment outcomes for malocclusion than those treated with CAT. Djeu et al. (2005) reported that FA improved proclination more effectively than CAT. They found that CA had statistically significantly lower root torque scores, whereas Hennessy (Year) reported no statistically significant difference between the two groups. In addition, Lanteri et al. (2018) showed that treatment with FA produced better outcomes for proclination than CAT, with improvement rates of 91.0% and 80.9%, respectively.

As CA are removable appliances, successful treatment depends heavily on patient compliance. In addition, each aligner produces only incremental tooth movement, meaning that greater time may be required to achieve optimal alignment. This may partly explain the limitations of CAT in controlling more complex tooth movement and proclination. By contrast, FA apply force through brackets over a restricted area, which can facilitate certain types of tooth movement during alignment, including tipping and proclination. Therefore, CAT appears to be appropriate for relatively simple

malocclusions and minor proclination, whereas FA are more suitable for more severe malocclusion and greater proclination.

4.2. Root resorption

The 10 included studies indicated that root resorption may occur during orthodontic treatment with either CA or FA, even when relatively light forces are used. However, CA were generally associated with less root resorption than FA in the maxillary and mandibular anterior teeth. Leite et al. (2012) reported that patients undergoing orthodontic treatment experienced root resorption in all cases. Although light force was used to produce tooth movement, patients treated with FA still demonstrated statistically significant root resorption in both the maxillary and mandibular central and lateral incisors (Yi et al., 2018).

Gay et al. (2017) likewise concluded that apical root resorption (ARR) was observed in 41.81% of teeth and was seen predominantly in the maxillary and mandibular incisors. This may be explained by the morphology of the incisors and the greater magnitude of tooth movement often required in these teeth. In the present review, the greatest extent of ARR was also observed in the maxillary and mandibular incisors. ARR may be explained in both physiological and pathological terms and primarily involves the loss of hard dental tissues from the root apex, including cementum and dentine (Gay et al., 2017).

Apical root resorption is common during treatment with FA, even when light force is applied, because orthodontic forces may induce inflammation in the periodontal ligament at the root apex. Hyalinised zones may also form at the root apex and are subsequently removed together with hard dental tissues such as cementum and dentine, resulting in permanent loss of tooth structure. In severe cases, this may lead to tooth loss, treatment failure, and reduced quality of life (Iglesias-Linares et al., 2018). The findings of the present review suggest that both CAT and treatment with FA are associated with mild root resorption, although CAT appears to result in less root resorption than FA. Accordingly, the application of light force during tooth movement is advisable in all cases.

4.3. Treatment duration

The included studies generally found that CAT was associated with a shorter treatment duration than treatment with FA. Zheng et al. (2017) also reported that CAT required less chair time and a shorter overall treatment duration than FA, as clinicians required less time to monitor tooth movement and patients were able to change the removable appliances themselves. However, Li et al. (2020) found that, in extraction cases, treatment duration was longer with CAT than with FA, possibly because CA have limitations in controlling tooth movement with each successive appliance. Consequently, clinicians must ensure that patients are motivated and compliant with both appliance wear and the prescribed schedule. Patients treated with FA may experience longer treatment duration together with irritation and discomfort from prolonged wear, which may make eating, speaking, and sleeping more difficult.

4.4. Pain perception and discomfort

Patients treated with FA commonly experienced pain during orthodontic treatment, particularly on the first day after appliance placement. CA were developed in part to reduce such problems and to improve patients' quality of life. The included studies showed that patients treated with either CA or FA experienced the highest level of pain on the first day after appliance placement, with

pain subsequently decreasing over the following days. However, patients treated with CA generally reported less pain and less disruption to daily life during treatment than those treated with FA.

Pain is a complex process influenced by multiple factors during orthodontic treatment and may affect both discomfort and quality of life (Krukemeyer et al., 2009). In addition, Patel et al. (2019) found that almost 30% of patients discontinued orthodontic treatment because of pain during the early stages of treatment. Furstman et al. (1970) also reported that inflammatory mediators are released within 24–48 hours after the application of orthodontic force, which may contribute to pain and discomfort.

These findings also suggest that pain may be influenced by patients' attitudes and personality traits. Clinicians should therefore inform patients about the pain and discomfort that may occur during orthodontic treatment, particularly in the first week after force application. They should also advise patients on strategies to manage discomfort in daily life. Moreover, Djeu et al. (2005) found that patients treated with CA had a significantly shorter treatment duration than those treated with FA, with CA = 16.8 months and FA = 20.4 months, $p = 0.0138$.

CA also appeared to improve aesthetics and patient satisfaction (Pacheco-Pereira, 2018). Some patients may avoid orthodontic treatment with braces because of aesthetic concerns. They may not wish brackets and wires to be visible while smiling or speaking, and this may contribute to discomfort and reduced confidence in daily life. Overall, these findings suggest that patients treated with CA had a better quality of life than those treated with FA.

4.5. Limitations of the study

Most of the included studies compared treatment outcomes between CAT and treatment with FA. However, the 23 studies did not examine all outcomes consistently. Some focused only on dental malalignment, whereas others investigated root resorption or quality of life. In addition, some studies did not directly compare effectiveness between the two groups, and some reported outcomes only for CA or only for FA. Consequently, the available evidence does not allow firm conclusions to be drawn regarding the comparative effectiveness of CAT and treatment with FA across all outcomes.

The studies also did not use identical systems of CA, such as Invisalign, or identical FA systems, such as 3M brackets. As a result, the findings may not provide a fully clear comparison of treatment outcomes between the two modalities.

Finally, some studies did not report treatment duration. This limits the precision of the analysis, as orthodontic treatment may produce different effects or outcomes at different time points.

5. Conclusion

In the included studies, both OGS scores and the PAR index were used to evaluate the effectiveness of malocclusion treatment. Both clear aligner treatment (CAT) and treatment with fixed appliances (FA) were found to be effective in the management of malocclusion. However, CAT appeared to be more suitable for mild malocclusion, whereas FA were effective in the treatment of mild to severe malocclusion. According to OGS scores and the PAR index, the CAT group had a lower rate of achieving great improvement in malalignment, malocclusion, and proclination than the FA group. Moreover, evidence relating to post-treatment stability suggested that patients treated with CA may be more prone to relapse than those treated with FA.

Both CAT and treatment with FA were associated with mild root resorption caused by orthodontic force, affecting at least two teeth in most cases and involving the maxillary and mandibular anterior teeth, although CAT was generally associated with less root resorption than FA. On the other hand, these findings support the view that patients treated with CA had a better quality of life than those treated with FA. They experienced shorter treatment duration, less pain, and less disruption in daily life. Therefore, irrespective of whether CAT or FA is used, clinicians should apply light force for tooth movement and adjust the appliance at an appropriate time and rate in order to minimise root resorption during treatment.

CAT offered advantages in terms of aesthetics, reduced pain, improved quality of life, and shorter treatment duration, whereas FA were more effective in achieving greater improvement in malocclusion and proclination, including better tooth alignment, occlusal and interproximal contacts, torque control, and increased transverse width. Clinicians should therefore consider the respective characteristics of these two treatment modalities when making treatment decisions. They should also explain the treatment process and the possible consequences of each approach to patients, so that the most appropriate treatment plan can be selected jointly.

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