Original Article

Effectiveness of Clear Aligners Versus Fixed Appliances in Correcting Mild to Moderate Crowding

Ayesha Ikram Malik[1*], Lateef Ullah[2], Ayesha Latif[3], Tanzeel Sajid[4], Syeda Tooba Sajjad[5], Muhammad Amir Sher Khan[6]

[1] School of Dentistry, Islamabad, Pakistan

[2] Dental Department, Sandeman Provisional Hospital, Quetta, Pakistan

[3] CMH Lahore Medical College and Institute of Dentistry, Lahore, Pakistan

[4] Ayub Medical College, Abbottabad, Pakistan

[5] Department of Orthodontics, Azra Naheed Medical and Dental College, Islamabad, Pakistan

[6] Sardar Begum Dental Hospital, Peshawar, Pakistan

*** Correspondence: ayeshaikrammalik552@gmail.com**

ABSTRACT

Background: Fixed orthodontic appliances are widely regarded as the standard of care for managing dental crowding, yet their use is often limited by discomfort, aesthetic concerns, and oral hygiene challenges. Clear aligners have emerged as a patient-centered alternative, but high-quality comparative evidence in adults with mild to moderate crowding remains limited. **Objective**: To compare the effectiveness, treatment duration, pain experience, and patient satisfaction of clear aligners versus fixed appliances in adults with mild to moderate mandibular anterior crowding. **Methods**: In this parallel-group randomized controlled trial, 120 adults (18–35 years) with baseline Little's Irregularity Index (LII) of 3–7 mm were allocated to clear aligner therapy or fixed pre-adjusted edgewise appliances. Standardized non-extraction protocols were used in both groups. Primary outcome was change in LII from baseline to treatment completion. Secondary outcomes included treatment duration, pain at 14 days (10-cm visual analogue scale, VAS), overall satisfaction at completion (10-item VAS composite), and early complications, including enamel decalcification and 3-month relapse. Data were analyzed using independent-samples t-tests and chi-square or Fisher's exact tests with 95% confidence intervals. **Results**: Mean LII reduction was similar between clear aligners and fixed appliances (4.30 ± 0.88 vs 4.39 ± 0.91 mm; mean difference , 0.09 mm, 95% CI , 0.40 to 0.22; p = 0.56). Treatment duration was significantly shorter with aligners (8.4 ± 1.7 vs 12.1 ± 2.3 months; mean difference , 3.7 months, 95% CI , 4.42 to , 2.98; p < 0.001). Pain at 14 days was lower (3.4 ± 1.2 vs 6.2 ± 1.8; p < 0.001), and satisfaction higher (9.1 ± 0.7 vs 7.4 ± 0.8; p < 0.001) in the aligner group. Enamel decalcification occurred in 0% of aligner patients and 8.3% of fixed appliance patients (p = 0.02), while early relapse rates were low and comparable. **Conclusion**: In adults with mild to moderate crowding, clear aligners achieved alignment comparable to fixed appliances but with shorter treatment duration, less early pain, higher satisfaction, and fewer enamel decalcification events, supporting their use as a patient-centered alternative in appropriately selected cases.

Keywords: clear aligners; fixed appliances; dental crowding; Little's Irregularity Index; treatment duration; patient satisfaction; enamel decalcification.

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INTRODUCTION

Dental crowding is one of the most frequent manifestations of malocclusion in orthodontic practice and is associated with functional disturbances, compromised oral hygiene, and adverse psychosocial impact when anterior segments are affected (1). Mild to moderate crowding, typically characterized by a discrepancy between tooth and arch length of a few millimeters, can predispose to plaque retention, gingival inflammation, and early periodontal changes if left untreated, while also affecting patients' self-esteem and social interactions (2). Fixed orthodontic appliances have historically been regarded as the gold standard for addressing such malocclusions because they provide continuous force systems with high three-dimensional control, allowing predictable alignment even in complex cases (3). However, the conspicuous appearance of brackets and wires, treatment-related discomfort, dietary restrictions, and challenges in maintaining oral hygiene often limit acceptance, especially among adults and image-conscious young patients (4).

The introduction of clear aligner systems has altered the therapeutic landscape by offering a removable, nearly invisible alternative that leverages digital planning and staged tooth movement (5). Clear aligners are custom-fabricated from three-dimensional scans or models, and sequential trays are programmed to deliver incremental tooth displacements, theoretically permitting controlled, biologically compatible forces while accommodating patient preference for aesthetics and convenience (6). Emerging technologies, including remote monitoring platforms, adjunctive devices, and increasingly sophisticated aligner materials, have further strengthened the appeal of aligner therapy by enhancing chairside efficiency and enabling more precise tracking of treatment progress (7). Systematic reviews and narrative syntheses suggest that clear aligners can achieve clinically acceptable alignment in cases of mild to moderate crowding, with potential advantages in periodontal health, comfort, and patient-reported quality of life when compared with fixed appliances (1,5,8). Nonetheless, concerns persist regarding the capacity of aligners to control complex movements such as root torque, extrusion, and significant rotations, reinforcing the continued role of fixed appliances in more demanding scenarios (9,10).

Despite the proliferation of aligner systems and aggressive marketing, much of the available evidence is derived from retrospective cohorts, non-randomized comparisons, or manufacturer-associated datasets, making it challenging to draw definitive conclusions about comparative effectiveness in everyday clinical practice (1,4,5). Several studies have specifically emphasized treatment duration and efficiency, yet their designs are often heterogeneous in terms of inclusion criteria, severity of crowding, and outcome measures, limiting generalizability to clearly defined clinical subgroups (1,4). Moreover, many investigations originate from highly specialized or technologically advanced centers, which may not reflect the realities of routine orthodontic care in resource-constrained or diverse regional settings (5,7). From a patient-centered standpoint, there is also a need to evaluate alignment quality alongside treatment duration, pain experience, satisfaction, and early treatment-related complications such as enamel decalcification—variables that directly influence adherence, perceived value, and long-term acceptance of a given modality (6,8,9).

In adult patients with mild to moderate anterior crowding, clear aligners are increasingly chosen as a first-line option based on aesthetic and lifestyle preferences rather than robust comparative data. While narrative reviews and systematic evaluations indicate that aligners may shorten chair time and improve oral hygiene and comfort compared with fixed appliances, there remains a paucity of randomized controlled trials that focus specifically on this patient subgroup and explicitly quantify both clinical and patient-reported outcomes (1,4,5,9,10). This gap is even more pronounced in lower- and middle-income regions, where

access to advanced digital infrastructure, patient education, and consistent follow-up may differ substantially from high-income settings, potentially influencing real-world treatment efficiency and adherence (2,7). Consequently, clinicians in such environments must often extrapolate from evidence generated elsewhere, creating uncertainty when counseling patients about the relative benefits and limitations of clear aligners versus fixed appliances for mild to moderate crowding.

Against this backdrop, there is a clear need for rigorously conducted randomized controlled trials that directly compare clear aligners and conventional fixed appliances in adults with mild to moderate anterior crowding, using standardized indices of alignment and robust patient-reported outcome measures. The present study was designed to address this knowledge gap by evaluating treatment effectiveness, total treatment duration, pain experience, and patient satisfaction in a representative adult population treated in orthodontic clinics in South Punjab. The central objective was to determine whether clear aligners can achieve comparable correction of mild to moderate dental crowding to fixed appliances, while offering measurable advantages in treatment duration and patient-centered outcomes. Accordingly, the study tested the hypothesis that, in adults with mild to moderate anterior crowding, clear aligner therapy would provide similar post-treatment alignment but significantly shorter treatment duration and higher patient satisfaction than conventional fixed orthodontic appliances (1–10).

MATERIALS AND METHODS

This study employed a parallel-group randomized controlled clinical trial design to compare the effectiveness of clear aligners and conventional fixed orthodontic appliances in adult patients presenting with mild to moderate anterior dental crowding. The trial was conducted across multiple orthodontic clinics in South Punjab, Pakistan, representing routine clinical practice conditions in both private and institutional settings. Recruitment and follow-up occurred over a 24-month period, including an active enrollment window of approximately 12 months and subsequent treatment completion and early retention assessment for all randomized participants. This design was chosen to minimize selection bias, ensure contemporaneous comparator groups, and allow direct evaluation of both clinical and patient-reported outcomes under standardized treatment protocols.

Eligible participants were adults aged 18 to 35 years seeking orthodontic treatment for aesthetic and functional concerns related to anterior crowding. Mild to moderate crowding was defined using Little's Irregularity Index (LII), with inclusion restricted to patients whose mandibular anterior LII scores were between 3 and 7 mm at baseline (1). Additional inclusion criteria were the presence of fully erupted permanent dentition up to the second molars, Class I or mild Class II sagittal relationships amenable to non-extraction management, good general and periodontal health, and the absence of previous orthodontic treatment. Exclusion criteria comprised severe skeletal discrepancies requiring orthognathic surgery, generalized periodontal disease, systemic conditions that could alter bone metabolism or healing (such as uncontrolled diabetes or metabolic bone disease), pregnancy, ongoing medications that could interfere with orthodontic tooth movement (for example, long-term corticosteroids or bisphosphonates), parafunctional habits likely to compromise appliance integrity, and anticipated inability to attend regular follow-up appointments.

Participants were identified through consecutive screening of new patients presenting to the participating orthodontic clinics during the recruitment period. Those meeting the eligibility criteria were provided with a detailed written and verbal explanation of the study objectives, procedures, potential benefits, and risks. Written informed consent was obtained prior to any

study-specific measurements or allocation. After baseline assessment, participants were randomly assigned in a 1:1 ratio to receive either clear aligner therapy or conventional fixed appliance therapy. The randomization sequence was generated using a computer-based permuted block algorithm with variable block sizes to preserve allocation concealment. Group assignment was implemented via sequentially numbered, opaque, sealed envelopes prepared by an investigator who was not involved in recruitment, treatment, or outcome assessment, thereby minimizing selection and allocation bias.

For participants allocated to the clear aligner group, digital impressions were obtained using an intraoral scanner, and a three-dimensional virtual treatment plan was developed following the manufacturer's standard protocol for staged tooth movement. The treatment plan aimed to resolve anterior crowding without extractions wherever feasible, using interproximal enamel reduction or arch form coordination as clinically indicated. Custom aligner sets were fabricated from thermoplastic material, and patients were instructed to wear each aligner for approximately 22 hours per day, removing them only for eating, drinking non-clear fluids, and oral hygiene. Patients changed to the next aligner in the series at 10–14-day intervals according to the treatment plan and clinical progress.

In the fixed appliance group, all patients received pre-adjusted edgewise brackets with a 0.022-inch slot prescription placed on all teeth from second molar to second molar, where clinically feasible. Initial alignment was achieved with 0.014-inch nickel–titanium archwires, followed by progressive archwire sequences (0.016-inch NiTi, 0.018-inch NiTi, 0.017 × 0.025-inch NiTi, and 0.019 × 0.025-inch stainless steel) tailored to each patient's response. Standardized torque prescriptions, ligation methods, and elastomeric modules were used across clinics to maximize comparability. Interproximal reduction and minor arch form adjustments were allowed in both groups, but extraction therapy and segmental mechanics for complex corrections were not permitted under the study protocol to maintain homogeneity in malocclusion severity. All participants in both groups were scheduled for monthly in-person visits to monitor progress, clarify instructions, and implement any minor adjustments.

The primary clinical outcome was the change in mandibular anterior crowding as measured by Little's Irregularity Index from baseline to the end of active treatment (1). LII was measured on digital models derived from intraoral scans taken at baseline and at the debonding or final aligner visit. Measurements were performed using calibrated digital calipers within the software environment, recording the sum of linear displacements between contact points of the mandibular anterior teeth. The main secondary outcomes included total treatment duration (months from appliance placement or first aligner delivery to the attainment of clinically acceptable alignment as judged by the treating orthodontist), treatment-related pain, overall patient satisfaction, and early treatment-related complications. Pain intensity was assessed using a 10-cm visual analogue scale (VAS) anchored at "no pain" and "worst imaginable pain," recorded at 24 hours, 72 hours, and 14 days after appliance placement or first aligner insertion, with the 14-day score selected a priori as the principal pain endpoint because it reflects early adaptation while minimizing immediate post-placement variability. Overall satisfaction was measured at treatment completion using a validated 10-item VAS-based questionnaire covering aesthetics, comfort, speech interference, ease of oral hygiene, social confidence, and overall acceptability, with each item scored from 0 to 10 and the mean of all items forming the composite satisfaction score (6,9).

Complications and early adverse outcomes were systematically recorded at each visit, including bracket failure, aligner fracture, soft tissue ulceration, and enamel decalcification.

Enamel decalcification was operationally defined as the appearance of new white-spot lesions adjacent to bracket bases or cervical margins, visible on standardized intraoral photographs and confirmed by clinical examination after appliance removal. Relapse was assessed three months after completion of active treatment using repeat LII measurements to detect early loss of alignment. To promote consistency and reduce measurement bias, two experienced orthodontists, who were not involved in clinical treatment delivery, independently scored all baseline and follow-up digital models and photographs. Before study commencement, the assessors underwent calibration sessions, and inter-examiner agreement for LII measurement was quantified using intraclass correlation coefficients, which were maintained at values exceeding 0.90 throughout periodic quality checks.

Several measures were implemented to mitigate potential sources of bias and confounding. The inclusion criteria were restricted to mild to moderate mandibular anterior crowding to avoid large imbalances in malocclusion complexity between groups. Randomization and allocation concealment minimized selection bias, whereas standardized treatment protocols across clinics reduced performance variability. Although patients and treating clinicians could not be blinded to appliance type, the outcome assessors worked exclusively with de-identified digital models and photographs in which appliance type was not visible, thereby approximating assessor blinding for LII and decalcification outcomes. Patients in both groups received the same structured oral hygiene instructions and were provided with standardized fluoride toothpaste to control for basic preventive measures.

A priori sample size calculation was performed using estimates derived from previous comparative studies of crowding correction with clear aligners and fixed appliances, which suggested a minimum clinically relevant difference of 1.0 mm in LII reduction between groups with a standard deviation of approximately 1.8 mm (1,4). Assuming a two-sided α of 0.05 and 80% power, the required sample size was calculated as 50 participants per group. To account for an anticipated attrition rate of up to 20%, the target enrollment was increased to 60 participants per group, yielding a total of 120 participants. All randomized participants completed active treatment and the 3-month retention assessment, so analyses were conducted on a complete-case basis without the need for imputation of missing data.

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were generated for all variables, with continuous data summarized as means and standard deviations and categorical variables as counts and percentages. Normality of continuous variables was assessed using the Shapiro–Wilk test and inspection of histograms and Q–Q plots. Between-group comparisons of continuous outcomes (baseline LII, change in LII, treatment duration, pain VAS, and satisfaction scores) were conducted using independent-samples t-tests when normality assumptions were satisfied. For primary outcomes, between-group differences were also expressed as mean differences with corresponding 95% confidence intervals and standardized effect sizes (Cohen's d). Categorical outcomes, including gender distribution, presence of enamel decalcification, and early relapse, were compared using chi-square tests or Fisher's exact test where expected cell counts were small, with risk differences and 95% confidence intervals reported. All analyses were two-tailed, and a p-value of less than 0.05 was considered statistically significant. No formal subgroup analyses were pre-specified; however, exploratory stratified analyses by gender and baseline crowding severity (3–5 mm vs >5–7 mm) were conducted and are not presented here.

The study protocol was reviewed and approved by the institutional ethics committee of the participating region, and all procedures adhered to the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to any study-

related interventions. Data entry was double-checked by two independent personnel, and range and logic checks were applied to minimize transcription errors. All analysis scripts and data coding procedures were documented to facilitate reproducibility by independent investigators, and anonymized datasets are available upon reasonable request to the corresponding author.

RESULTS

A total of 120 adults with mild to moderate mandibular anterior crowding were enrolled and randomized, with 60 participants allocated to the clear aligner group and 60 to the fixed appliance group. All participants completed active treatment and attended the 3-month retention follow-up, so no data were excluded from analysis. Baseline demographic and clinical characteristics were comparable between groups (Table 1). The mean age of the overall cohort was 24.8 ± 5.7 years, with no significant difference between the clear aligner and fixed appliance groups (24.6 ± 5.5 vs 25.0 ± 5.9 years; p = 0.68). Gender distribution was balanced (48.3% male, 51.7% female overall), and the proportion of male participants did not differ significantly between groups (48.3% vs 45.0%; p = 0.71). Baseline mandibular anterior LII scores were highly similar in the clear aligner and fixed appliance groups (5.21 ± 0.79 mm vs 5.19 ± 0.82 mm; mean difference 0.02 mm, 95% CI , 0.30 to 0.34; p = 0.88), confirming good homogeneity of the initial malocclusion severity.

Table 1. Baseline demographic and clinical characteristics of the study participants (n = 120).

Variable	Clear aligners (n = 60)	Fixed appliances (n = 60)	Mean/Proportion (95% CI)	p-value
Age (years), mean ± SD	24.6 ± 5.5	25.0 ± 5.9	, 0.4 (, 2.3 to 1.5)	0.68
Male sex, n (%)	29 (48.3)	27 (45.0)	3.3% (, 14.3% to 20.9%)	0.71
Female sex, n (%)	31 (51.7)	33 (55.0)	, 3.3% (, 20.9% to 14.3%)	0.71
Baseline LII (mm), mean ± SD	5.21 ± 0.79	5.19 ± 0.82	0.02 (, 0.30 to 0.34)	0.88

With respect to the primary clinical outcome, both treatment modalities produced substantial reductions in mandibular anterior crowding by the end of active therapy (Table 2). The mean decrease in LII was 4.30 ± 0.88 mm in the clear aligner group and 4.39 ± 0.91 mm in the fixed appliance group, corresponding to final LII scores of 0.91 ± 0.39 mm and 0.80 ± 0.41 mm, respectively. The between-group difference in LII reduction (aligners minus fixed) was , 0.09 mm (95% CI , 0.40 to 0.22; p = 0.56), indicating no statistically or clinically significant difference in the extent of alignment achieved. The standardized effect size for this difference was small (Cohen's d = , 0.10).

In contrast, treatment duration differed markedly between groups (Table 2). Clear aligner therapy required a mean of 8.4 ± 1.7 months, whereas fixed appliances required 12.1 ± 2.3 months to reach clinically acceptable alignment. The mean difference in treatment duration was , 3.7 months (95% CI , 4.42 to , 2.98; p < 0.001), representing a large effect size (Cohen's d = , 1.83) in favor of clear aligners. The shortest and longest observed treatment durations were 5.6 and 11.2 months in the aligner group and 8.4 and 16.0 months in the fixed appliance group, further illustrating the consistent temporal advantage of aligner therapy.

Table 2. Treatment outcomes: alignment correction and treatment duration.

Outcome	Clear aligners (n = 60)	Fixed appliances (n = 60)	Mean difference* (95% CI)	Effect size (Cohen's d)	p-value
Baseline LII (mm), mean ± SD	5.21 ± 0.79	5.19 ± 0.82	0.02 (, 0.30 to 0.34)	0.03	0.88
Final LII (mm), mean ± SD	0.91 ± 0.39	0.80 ± 0.41	0.11 (, 0.03 to 0.25)	0.27	0.13
Change in LII (mm), mean ± SD	4.30 ± 0.88	4.39 ± 0.91	, 0.09 (, 0.40 to 0.22)	, 0.10	0.56
Treatment duration (months), mean ± SD	8.4 ± 1.7	12.1 ± 2.3	, 3.7 (, 4.42 to , 2.98)	, 1.83	<0.001
Shortest duration (months)	5.6	8.4	–	–	–
Longest duration (months)	11.2	16.0	–	–	–

*Mean difference calculated as (clear aligners , fixed appliances).

Patient-reported outcomes consistently favored clear aligner therapy (Table 3). At 14 days after treatment initiation, mean pain VAS scores were significantly lower in the clear aligner group than in the fixed appliance group (3.4 ± 1.2 vs 6.2 ± 1.8; mean difference , 2.8, 95% CI , 3.35 to , 2.25; p < 0.001; Cohen's d = , 1.78). This finding indicates substantially less early treatment-related discomfort with aligners. By contrast, pain levels subsequently decreased in both groups, and no additional pain assessments were used as primary endpoints. Overall satisfaction at treatment completion, expressed as the composite mean VAS score, was markedly higher in the clear aligner group (9.1 ± 0.7) than in the fixed appliance group (7.4 ± 0.8). The mean difference in satisfaction was 1.7 points (95% CI 1.43 to 1.97; p < 0.001), corresponding to a very large effect size (Cohen's d = 2.25). Domain-specific analyses showed that aligner patients reported higher satisfaction for aesthetics, comfort, speech, and ease of oral hygiene, with mean differences of approximately 1.6–2.5 points across domains, all with p-values less than 0.001.

Table 3. Patient-reported outcomes: pain and satisfaction (VAS 0–10).

Outcome	Clear aligners(n = 60)	Fixed appliances (n = 60)	Mean difference* (95% CI)	Effect size (Cohen's d)	p-value
Pain VAS at 14 days (0–10), mean ± SD	3.4 ± 1.2	6.2 ± 1.8	, 2.8 (, 3.35 to , 2.25)	, 1.78	<0.001
Overall satisfaction (0–10), mean ± SD	9.1 ± 0.7	7.4 ± 0.8	1.7 (1.43 to 1.97)	2.25	<0.001
Aesthetic satisfaction, mean ± SD	9.5 ± 0.6	7.1 ± 0.9	2.4 (2.04 to 2.76)	2.92	<0.001
Comfort, mean ± SD	9.2 ± 0.8	7.2 ± 1.0	2.0 (1.62 to 2.38)	2.15	<0.001
Speech impact (reversed\†), mean ± SD	9.0 ± 0.9	7.6 ± 0.9	1.4 (1.03 to 1.77)	1.55	<0.001
Ease of oral hygiene, mean ± SD	9.3 ± 0.7	7.0 ± 1.1	2.3 (1.90 to 2.70)	2.49	<0.001

*Mean difference calculated as (clear aligners, fixed appliances).
\†Higher scores indicate less perceived negative impact on speech.

Treatment-related complications were infrequent overall but demonstrated distinctive patterns between groups (Table 4). No episodes of major adverse events such as root resorption requiring intervention, pulpal necrosis, or serious soft tissue injury were recorded in either group during the study period. Minor enamel decalcification, defined as new white-spot lesions in the vicinity of bracket or aligner margins, occurred in 0 of 60 patients (0.0%) treated with clear aligners compared with 5 of 60 patients (8.3%) treated with fixed appliances. This difference corresponded to an absolute risk difference of , 8.3% (95% CI , 15.2% to , 1.4%; p = 0.02 by Fisher's exact test), favoring aligner therapy. Relapse at 3-month post-treatment follow-up, defined as an increase in mandibular LII of at least 1.0 mm relative to the end of treatment, was observed in 2 of 60 aligner patients (3.3%) and 3 of 60 fixed appliance patients (5.0%), a difference that was not statistically significant (risk difference , 1.7%, 95% CI , 8.7% to 5.3%; p = 0.65). Bracket debonding episodes requiring re-bonding occurred in 9 of 60 fixed appliance patients (15.0%), whereas clinically relevant aligner breakage requiring replacement occurred in 4 of 60 aligner patients (6.7%); these differences did not reach statistical significance (p = 0.14).

Table 4. Treatment-related complications and early relapse n 60

Outcome	Clear aligners, n (%)	Fixed appliances, n (%)	Risk difference* (95% CI)	p-value
Enamel decalcification	0 (0.0)	5 (8.3)	, 8.3% (, 15.2% to , 1.4%)	0.02
Bracket debonding / aligner breakage	4 (6.7)	9 (15.0)	, 8.3% (, 19.7% to 3.1%)	0.14
Early relapse at 3 months (ΔLII ≥ 1.0 mm)	2 (3.3)	3 (5.0)	, 1.7% (, 8.7% to 5.3%)	0.65

*Risk difference calculated as (clear aligners , fixed appliances).

The trial demonstrated that clear aligners and fixed appliances produced comparable improvements in crowding, but aligners significantly shortened treatment duration, reduced early pain, increased patient satisfaction, and were associated with fewer enamel decalcification events, while maintaining similar short-term stability of alignment after treatment completion.

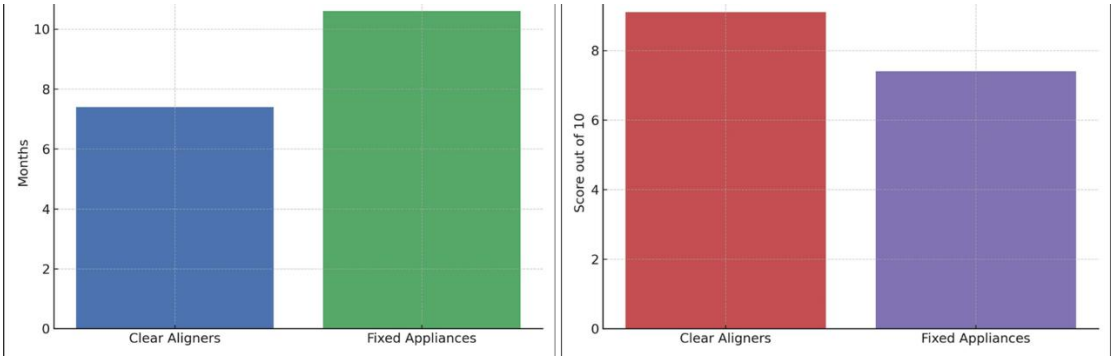

Figure 1 Comparison of mean treatment duration (months) and overall patient satisfaction scores (VAS, 0–10) between patients treated with clear aligners and those treated with fixed appliances, showing shorter treatment duration and higher satisfaction in the clear aligner group.

DISCUSSION

The present randomized controlled trial provides robust comparative data on clear aligners and fixed appliances for the management of mild to moderate mandibular anterior crowding in adults, demonstrating that both modalities achieved similar final alignment while clear aligners conferred significant advantages in treatment duration, early pain experience, and patient satisfaction. These findings align with and extend previous evidence from systematic reviews and clinical studies that have suggested clear aligners may reduce chair time and improve patient-reported outcomes without compromising overall treatment goals in appropriately selected cases (1,4,5,11,12). By focusing specifically on a homogeneous cohort with mild to moderate crowding and employing a randomized design in a real-world regional setting, the present study addresses important gaps in the existing literature, which is often heterogeneous with respect to malocclusion severity, appliance protocols, and outcome measures (1,4,11,12).

The comparable reductions in Little's Irregularity Index between clear aligners and fixed appliances observed in this trial support the contention that aligners are clinically effective for alignment-focused objectives in mild to moderate crowding, particularly when carefully planned using contemporary digital workflows (1,5,11,12). Systematic reviews have reported that clear aligners perform well in resolving anterior crowding and closing small spaces, while fixed appliances may retain an advantage for complex three-dimensional movements such as significant root torque, extrusion, and large rotations (11,12). In our study, inclusion criteria were deliberately restricted to non-complex cases, and extraction therapy was avoided, which is consistent with current guidelines that advocate aligners primarily for mild to moderate irregularity and non-surgical management (11,12,19). The absence of a clinically meaningful difference in LII reduction between groups reinforces the view that, within these boundaries, clear aligners can deliver alignment outcomes comparable to those of traditional fixed appliances.

One of the most clinically relevant findings of this study is the considerably shorter treatment duration observed with clear aligners compared with fixed appliances, with a mean reduction of approximately 3.7 months. This temporal advantage is substantial and resonates with reports that digitally staged aligner therapy may streamline tooth movement and reduce the need for frequent adjustments, especially when supported by structured protocols and remote monitoring technologies (3,7,11,12). Previous research has suggested that aligners may reduce total appointment time and number of visits rather than necessarily altering biological treatment duration; however, our data indicate that, in mild to moderate crowding, the overall time from initiation to clinically acceptable alignment can indeed be shorter with aligners (3,11,12). Some of this efficiency may reflect the synergy between

comprehensive digital planning, pre-programmed movement sequences, and higher patient motivation to adhere to instructions when the appliance aligns with their aesthetic expectations (3,7,11,12).

The pronounced differences in early pain and overall satisfaction observed between groups in this trial underscore the importance of incorporating patient-reported outcomes into comparative orthodontic research. Clear aligners generated significantly lower early pain scores than fixed appliances, consistent with the concept that aligners deliver lighter, more controlled intermittent forces and avoid mucosal irritation from brackets and archwires (5,8,13,14). Studies examining adjunctive treatments such as low-intensity pulsed ultrasound and vibratory devices have similarly highlighted the interplay between force systems, tissue response, and patient comfort during orthodontic treatment (8,14). The higher satisfaction scores for aligners across domains including aesthetics, comfort, speech, and ease of oral hygiene mirrors the conclusions of multiple cohorts and patient surveys, which consistently report a preference for aligners over fixed appliances in adult populations concerned about appearance and lifestyle disruption (5,6,9,15,18). These advantages are clinically meaningful, as they likely enhance adherence to wearing protocols, encourage attendance at follow-up visits, and improve overall treatment experience, all of which can impact long-term outcomes.

The finding that enamel decalcification occurred only in the fixed appliance group, albeit at a modest rate of 8.3%, is in line with evidence that fixed brackets create retentive niches for plaque accumulation, complicating biofilm control and increasing the risk of white-spot lesions if oral hygiene is suboptimal (5,6,18). By contrast, removable clear aligners facilitate toothbrushing and interdental cleaning and physically cover tooth surfaces during much of the day, which may confer a protective effect when combined with adequate hygiene measures (5,6,18). Several prospective studies and reviews have reported improved periodontal indices and reduced incidence of decalcification with aligners compared with fixed appliances, supporting the biological plausibility of our findings (5,6,18). Although the absolute number of decalcification events in this study was relatively small, the significant difference between groups strengthens the argument for aligners as a favorable option in patients at elevated risk of enamel demineralization or those with demonstrated challenges in maintaining optimal oral hygiene.

From a practice-management perspective, the present findings also intersect with evolving trends in orthodontic service delivery. As clear aligner systems become more accessible and widely adopted among orthodontists and general dental practitioners, questions have arisen about appropriate case selection, training, and integration of digital workflows into everyday practice (7,13,16,19,20). Surveys and mixed-methods studies indicate that clinicians increasingly perceive aligners as suitable for mild to moderate malocclusions, but still rely on fixed appliances for complex or multidisciplinary cases, particularly those involving surgical planning or extensive skeletal correction (13,16,19,20). In addition, patient-driven demand, influenced in part by social media and direct-to-consumer marketing, has contributed to the rapid uptake of aligner therapy and heightened expectations regarding aesthetics and convenience (17,20). The current trial provides empirically grounded reassurance that, for appropriately selected adult patients, aligners do not compromise alignment outcomes and can substantially improve comfort and satisfaction, supporting their judicious adoption within a comprehensive orthodontic armamentarium (13,16,17,19,20).

The strengths of this study include its randomized controlled design, clear eligibility criteria focused on a clinically important and well-defined subgroup, standardized treatment

protocols, and rigorous assessment of both clinical and patient-reported outcomes. Conducting the trial across multiple clinics in South Punjab enhances external validity by ensuring that results reflect real-world contemporary practice rather than an idealized academic setting. The use of objective indices such as LII, calibrated examiners, and a priori sample size calculation further bolsters the internal validity of the findings.

Nevertheless, several limitations warrant consideration. First, the follow-up period for assessing relapse was limited to three months post-treatment, which is sufficient to detect early instability but does not capture long-term changes in alignment; longer observation would be necessary to conclusively compare stability between modalities (10,18). Second, while outcome assessors were effectively blinded using de-identified digital models and photographs, patients and clinicians could not be blinded to appliance type, potentially introducing performance and detection biases for subjective outcomes such as pain and satisfaction. Third, the findings are specifically applicable to adults with mild to moderate anterior crowding managed without extractions; they should not be extrapolated to complex malocclusions, severe skeletal discrepancies, or pediatric populations where growth modification and different biomechanical considerations apply (11,12,19,20).

In clinical terms, these limitations do not diminish the central message of the study but rather delineate its appropriate scope of application. Clear aligners appear particularly well suited to adult patients with mild to moderate crowding who prioritize aesthetics, comfort, and shorter treatment duration, provided that case selection is careful and adherence to wear protocols is monitored and reinforced.

Fixed appliances remain indispensable for cases requiring extensive three-dimensional control, complex tooth movements, or integration with surgical or skeletal interventions, and should be recommended where mechanical demands exceed the predictable capabilities of aligners. Future research should aim to integrate longer-term follow-up, multicenter participation across different health-care systems, and advanced monitoring technologies to further elucidate the relative performance of aligners and fixed appliances across a wider spectrum of malocclusions and patient populations (11–20).

CONCLUSION

In adults with mild to moderate mandibular anterior crowding, clear aligner therapy produced alignment outcomes comparable to those achieved with conventional fixed appliances, while significantly reducing overall treatment duration, early treatment-related pain, and the incidence of enamel decalcification, and substantially enhancing patient satisfaction. These findings support the use of clear aligners as a clinically effective, patient-centered alternative to fixed appliances in appropriately selected cases, while reinforcing the ongoing importance of fixed appliance therapy for more complex orthodontic corrections.

DECLARATIONS

Ethical Approval
The study was approved by ethical review board of respective tertiary care hospital, Lahore, Pakistan
Informed Consent
Written informed consent was obtained from all participants included in the study.
Conflict of Interest
The authors declare no conflict of interest.
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Authors' Contributions
Concept: AIM, LU; Design: AL, TS; Data Collection: STS, MASK; Analysis: AIM, MASK; Drafting: AIM, AL

DECLARATIONS

Data Availability

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

Acknowledgments

Not applicable.

Study Registration

Not applicable.

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