

COMPARISON OF ORAL HYGIENE STATUS AND GINGIVAL HEALTH BETWEEN PATIENTS WEARING FIXED ORTHODONTIC APPLIANCES AND CLEAR ALIGNERS: A COMPARATIVE CROSS-SECTIONAL STUDY

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Abstract

Background: Orthodontic treatment can influence oral hygiene and gingival health due to changes in plaque retention, oral hygiene practices, and access to tooth surfaces. Fixed orthodontic appliances may create additional plaque-retentive areas around brackets and archwires, potentially increasing the risk of gingival inflammation. Clear aligners, in contrast, are removable and may facilitate oral hygiene procedures, although their use can also alter the oral environment. Comparing oral hygiene status and gingival health between patients using these two treatment modalities can provide valuable insight into their effects on periodontal health. Therefore, this study aimed to compare oral hygiene status and gingival health among patients wearing fixed orthodontic appliances and clear aligners. To compare oral hygiene status and gingival health between patients undergoing orthodontic treatment with fixed appliances and those using clear aligners.

Methods: This comparative cross-sectional study included 176 orthodontic patients aged 13–31 years (110 with fixed appliances and 66 with clear aligners) at Saidu Group of Teaching Hospital, Swat, Khyber Pakhtunkhwa, Pakistan from January 2025 to June 2026. Participants completed a structured questionnaire on demographics, treatment characteristics, oral hygiene practices, diet, tobacco use and gingival symptoms, followed by a clinical examination recording the Silness–Löe plaque index, Löe–Silness gingival index, bleeding on probing, probing pocket depth, calculus and white spot lesions. Groups were compared using the Mann–Whitney U test and chi-square tests, and multivariable linear

regression adjusted for age, sex, treatment duration and hygiene behaviors. Significance was set at $p < 0.05$.

Results: The fixed appliance group had higher mean plaque index (1.80 ± 0.53 vs. 1.44 ± 0.61 ; mean difference 0.36, 95% CI 0.18–0.54; $p < 0.001$) and gingival index (1.44 ± 0.47 vs. 1.15 ± 0.47 ; mean difference 0.29, 95% CI 0.15–0.44; $p < 0.001$). Bleeding on probing (74.5% vs. 45.5%, $p < 0.001$), calculus (56.4% vs. 37.9%, $p = 0.018$) and white spot lesions (35.5% vs. 18.2%, $p = 0.035$) were more frequent with fixed appliances, whereas probing pocket depth did not differ significantly (2.44 ± 0.46 mm vs. 2.32 ± 0.43 mm; $p = 0.091$). Self-reported brushing, interdental cleaning, mouthwash use and professional cleaning were similar between groups. After adjustment, clear aligner use remained independently associated with lower plaque ($\beta = -0.34$, 95% CI -0.51 to -0.16) and gingival ($\beta = -0.30$, 95% CI -0.44 to -0.15) index scores. Overall, 63.6% of participants had poor hygiene status and only 4.0% had clinically healthy gingiva.

Conclusion: Patients with clear aligners had significantly better plaque control and gingival health than those with fixed appliances, independent of measured hygiene behaviors, although hygiene was suboptimal in both groups. Appliance-specific oral hygiene reinforcement is recommended for all orthodontic patients.

INTRODUCTION

Orthodontic treatment is commonly undertaken in adolescents and young adults, yet appliances placed on the teeth can compromise oral hygiene. Brackets, bands and archwires create retentive sites for dental plaque and make mechanical cleaning more difficult, predisposing patients to gingival inflammation, calculus accumulation and demineralization around the appliance.[1,2] Because plaque accumulation is the principal etiological factor in gingivitis, the ability of a patient to maintain effective plaque control during treatment is a central determinant of periodontal health.[1]

Clear aligners have become a widely used alternative to conventional fixed appliances. As they are removable, patients can brush and floss without the obstruction of brackets and wires, which is expected to facilitate plaque control.[2,3] Several systematic reviews have reported lower plaque and gingival indices in aligner patients. A meta-analysis of nine studies reported pooled mean differences of -0.53 for plaque index and -0.27 for gingival index in favor of clear aligners,[3] and a recent meta-analysis of 28

studies reported comparable differences (-0.44 and -0.23 , respectively) alongside lower probing depth.[4] Other reviews, however, have concluded that the evidence remains insufficient because of heterogeneity, small samples and methodological limitations,[5] and the magnitude and clinical importance of the difference vary between studies and populations. A subsequent review of systematic reviews similarly concluded that clear aligners are associated with more favorable, although modest, periodontal outcomes than fixed appliances,[10] and cross-sectional studies comparing aligners with different fixed bracket systems have reported consistent directional differences in periodontal indices.[11,12] Quantitative light-induced fluorescence studies have further shown greater enamel demineralization around fixed appliances than aligners, supporting a similar advantage for white spot lesion prevention.[13]

Differences between appliance types may also reflect patient-related factors, such as brushing and interdental cleaning habits, professional care, diet, tobacco use and treatment duration, rather than the appliance itself. Few studies have

evaluated clinical indices alongside patients' self-reported hygiene behaviors in the same sample, particularly in South Asian populations. The present study therefore compared oral hygiene status and gingival health between patients wearing fixed orthodontic appliances and clear aligners, and examined whether differences persisted after accounting for demographic and behavioral factors.

Methods

Study design and setting

This comparative cross-sectional study was conducted at Department of Orthodontics, Saidu Group of Teaching Hospital, Swat, Khyber Pakhtunkhwa, Pakistan from January 2025 to June 2026 and is reported in accordance with the STROBE guidelines.[6] The study was approved by the Institutional Ethical Review Committee, Saidu Group of Teaching Hospital, Swat (reference no. SGTH/ERC/2024-187, dated 10 December 2024).

Participants and sampling

A total of 176 orthodontic patients were enrolled using non-probability consecutive sampling. Sample size was calculated using G*Power version 3.1.9.7, based on an anticipated mean difference in gingival index of 0.30 (SD 0.5) between fixed appliance and clear aligner users reported in prior comparative studies, a two-sided alpha of 0.05 and power of 80%, yielding a minimum requirement of 45 participants per group; recruitment exceeded this minimum in both groups. Patients were eligible if they were undergoing active orthodontic treatment with either conventional fixed appliances or clear aligners and provided consent. Inclusion criteria were: patients aged 12–35 years; currently undergoing active orthodontic treatment with either conventional fixed appliances or clear aligners for a minimum duration of 6 months; presence of at least 20 erupted permanent teeth; and willingness to complete the questionnaire and undergo a clinical oral examination. Exclusion criteria were: systemic diseases known to affect periodontal status (e.g., uncontrolled

diabetes mellitus, blood dyscrasias or immunosuppressive disorders); use of antibiotics, anti-inflammatory drugs or chlorhexidine mouthwash within the preceding month; pregnancy or lactation; pre-existing periodontal disease or periodontal treatment before starting orthodontic therapy; and concurrent or hybrid use of both fixed appliances and clear aligners during the study period. Written informed consent was obtained from all participants (and from parents or guardians of participants younger than 18 years, with assent from the minor) in accordance with institutional ethical guidelines. All 176 participants consented, and no records had missing data. Participants were classified into a fixed appliance group (n=110) and a clear aligner group (n=66) according to the appliance currently in use.

Questionnaire

Data were collected using a structured, pre-tested questionnaire comprising 37 items. Domains included demographic characteristics (age, sex, residence, educational level); treatment characteristics (appliance type, treatment duration, appointment frequency, receipt of hygiene instructions, professional cleaning frequency); oral hygiene practices (brushing frequency and duration, toothbrush and toothpaste type, dental floss, interdental brush, mouthwash and tongue cleaning); appliance-specific items (difficulty cleaning and food trapping for fixed appliances; wear time, removal before eating, brushing before reinsertion, aligner cleaning frequency and perceived difficulty for aligners); dietary habits (sugary snacks and beverages, sticky or hard foods); tobacco and vaping use; and gingival symptoms (gum bleeding, swelling, redness, halitosis, sensitivity and white spots). The questionnaire was developed by the study investigators, informed by instruments used in previous comparative studies of appliance-related oral hygiene behavior, and translated into Urdu with back-translation into English to confirm semantic equivalence. It was pilot-tested on 20 orthodontic patients who were not included in the final analysis, and showed

acceptable internal consistency (Cronbach's $\alpha = 0.78$).

Clinical examination

A clinical examination was performed by a single calibrated examiner (a postgraduate resident in orthodontics) under natural daylight using a mouth mirror, periodontal probe (UNC-15) and cotton pellets. Plaque accumulation was scored using the Silness-Löe plaque index (0-3),[7] and gingival inflammation using the Löe-Silness gingival index (0-3),[8] each expressed as a mean score per participant. Bleeding on probing was recorded as present or absent,[9] probing pocket depth was measured in millimetres, and calculus was recorded as present or absent. Six sites were examined per participant (the Ramfjord index teeth: 16, 21, 24, 36, 41 and 44). Gingival condition was categorized as healthy, mild, moderate or severe inflammation, and overall hygiene status as good, fair or poor (plaque index: good <1.0 , fair $1.0-1.9$, poor ≥ 2.0 ; gingival index: healthy 0, mild $0.1-1.0$, moderate $1.1-2.0$, severe $2.1-3.0$). Intra-examiner reliability, assessed by re-examining 20 randomly selected participants two weeks later, showed excellent agreement (intraclass correlation coefficient = 0.91 for plaque index and 0.89 for gingival index).

Statistical analysis

Data were analyzed using Python (SciPy and statsmodels). Continuous variables are presented as mean $\pm$ standard deviation (SD) and median (interquartile range). Because the distributions of age and gingival index departed from normality in at least one group (Shapiro-Wilk $p < 0.05$), between-group differences in continuous variables were tested with the Mann-Whitney U

test; mean differences are reported with 95% confidence intervals (Welch method) and Cohen's d. Categorical variables are presented as frequencies and percentages and compared with the chi-square test, Fisher's exact test (2×2 tables with small expected counts) or a Monte Carlo permutation test (larger tables with expected counts below 5). Associations between clinical indices and treatment duration were assessed with the Kruskal-Wallis test, and the plaque-gingival index correlation with Spearman's coefficient. Multivariable linear regression models for plaque index and gingival index included appliance type, age, sex, treatment duration, brushing frequency, professional cleaning frequency, smoking, flossing, interdental brush use and receipt of hygiene instructions. A two-sided p -value < 0.05 was considered statistically significant.

Results

Participant characteristics

The sample comprised 176 patients (mean age 19.73 ± 4.19 years; range 13-31 years), of whom 110 (62.5%) were female and 120 (68.2%) lived in urban areas. Overall, 110 patients (62.5%) had fixed appliances and 66 (37.5%) had clear aligners. Patients with aligners were older (20.62 ± 3.97 vs. 19.20 ± 4.24 years; $p = 0.017$) and less likely to have a secondary education or below (Table 1). Sex, residence, treatment duration, receipt of hygiene instructions, professional cleaning frequency, smoking and vaping did not differ significantly between the groups. Appointment intervals differed markedly: 70.0% of fixed appliance patients were reviewed every 2-4 weeks, compared with 13.6% of aligner patients ($p < 0.001$).

Table 1. Demographic and treatment characteristics by appliance type

Characteristic	Fixed (n=110)	Clear aligner (n=66)	p-value
Age (years), mean $\pm$ SD	19.20 ± 4.24	20.62 ± 3.97	0.017†
Female sex	65 (59.1)	45 (68.2)	0.228
Urban residence	70 (63.6)	50 (75.8)	0.095

Characteristic	Fixed (n=110)	Clear aligner (n=66)	p-value
Education: secondary or below	30 (27.3)	29 (43.9)	0.030
Treatment duration >12 months	43 (39.1)	27 (40.9)	0.483
Visit interval 2–4 weeks	77 (70.0)	9 (13.6)	<0.001
Received hygiene instructions	67 (60.9)	39 (59.1)	0.811
Professional cleaning every 3–6 months	38 (34.5)	25 (37.9)	0.388
Current smoker	18 (16.4)	9 (13.6)	0.627
Current vaper	9 (8.2)	10 (15.2)	0.149

Data are n (%) unless stated. † Mann–Whitney U test; other p-values from chi-square/Fisher's exact tests. The education and appointment-interval p-values compare all response categories; the rows show one category. Monte Carlo exact p-values were used where expected counts were <5.

Plaque and gingival indices

Patients with fixed appliances had significantly higher plaque index (1.80 ± 0.53 vs. 1.44 ± 0.61 ; mean difference 0.36, 95% CI 0.18 to 0.54; $p < 0.001$; $d = 0.64$) and gingival index scores (1.44 ± 0.47 vs. 1.15 ± 0.47 ; mean difference 0.29, 95% CI 0.15 to 0.44; $p < 0.001$; $d = 0.63$) than

aligner patients (Table 2, Figure 1). Probing pocket depth was slightly greater with fixed appliances, but the difference was not statistically significant ($p = 0.091$). The plaque and gingival indices were strongly correlated (Spearman $\rho = 0.69$, $p < 0.001$).

Table 2. Clinical indices by appliance type

Variable	Fixed, mean SD	Fixed, median (IQR)	Aligner, mean SD	Aligner, median (IQR)	Mean difference (95% CI)	d	p-value
Plaque index (0–3)	1.80 ± 0.53	1.80 (1.32–2.20)	1.44 ± 0.61	1.40 (0.93–1.80)	0.36 (0.18 to 0.54)	0.64	<0.001
Gingival index (0–3)	1.44 ± 0.47	1.40 (1.12–1.77)	1.15 ± 0.47	1.10 (0.90–1.40)	0.29 (0.15 to 0.44)	0.63	<0.001
Probing pocket depth (mm)	2.44 ± 0.46	2.40 (2.12–2.70)	2.32 ± 0.43	2.30 (2.00–2.60)	0.12 (-0.02 to 0.26)	0.091	

Mean difference = fixed minus aligner; 95% CI by Welch method; p-values from Mann–Whitney U test; d = Cohen's d.

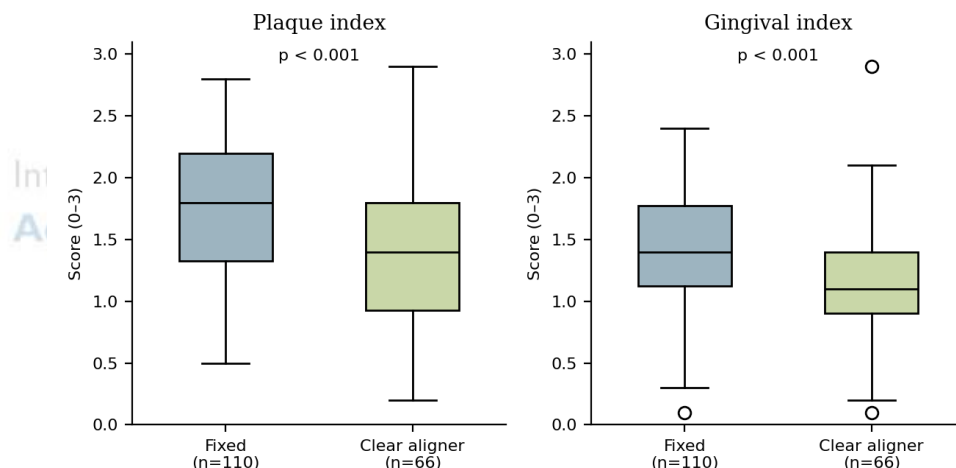


Figure 1. Plaque index and gingival index in patients with fixed appliances and clear aligners (Mann-Whitney U test).

Clinical and symptomatic outcomes

Bleeding on probing was present in 74.5% of fixed appliance patients and 45.5% of aligner patients ($p < 0.001$), and calculus in 56.4% and 37.9%, respectively ($p = 0.018$) (Table 3, Figure 2). The distribution of gingival condition differed significantly ($p < 0.001$): moderate or severe inflammation affected 82.7% of fixed appliance patients versus 53.0% of aligner patients, and only 7 of 176 participants (4.0%) had clinically

healthy gingiva (Figure 3). Overall hygiene status was rated poor in 73.6% of the fixed group and 47.0% of the aligner group ($p < 0.001$; Figure 4). Self-reported gum swelling (71.8% vs. 33.3%; $p < 0.001$) and redness (61.8% vs. 39.4%; $p = 0.004$) and visible white spot lesions (35.5% vs. 18.2%; $p = 0.035$) were more common with fixed appliances. Bleeding while brushing, halitosis and pain or sensitivity did not differ significantly.

Table 3. Clinical findings and gingival symptoms by appliance type

Outcome	Fixed (n=110)	Clear aligner (n=66)	p-value
Bleeding on probing present	82 (74.5)	30 (45.5)	<0.001
Calculus present	62 (56.4)	25 (37.9)	0.018
Gingival condition			<0.001
Healthy	3 (2.7)	4 (6.1)	
Mild inflammation	16 (14.5)	27 (40.9)	
Moderate inflammation	73 (66.4)	32 (48.5)	
Severe inflammation	18 (16.4)	3 (4.5)	
Overall hygiene status			<0.001
Good	2 (1.8)	5 (7.6)	
Fair	27 (24.5)	30 (45.5)	
Poor	81 (73.6)	31 (47.0)	

Outcome	Fixed (n=110)	Clear aligner (n=66)	p-value
Gum swelling (self-reported)	79 (71.8)	22 (33.3)	<0.001
Gum redness (self-reported)	68 (61.8)	26 (39.4)	0.004
Bleeding on brushing: always/frequently	57 (51.8)	29 (43.9)	0.150
Bad breath: frequently/sometimes	51 (46.4)	38 (57.6)	0.151
Pain/sensitivity	63 (57.3)	46 (69.7)	0.100
White spot lesions (visible)	39 (35.5)	12 (18.2)	0.035

Data are n (%). p-values from chi-square, Fisher's exact or Monte Carlo exact tests; for multi-category variables the p-value compares the whole distribution.

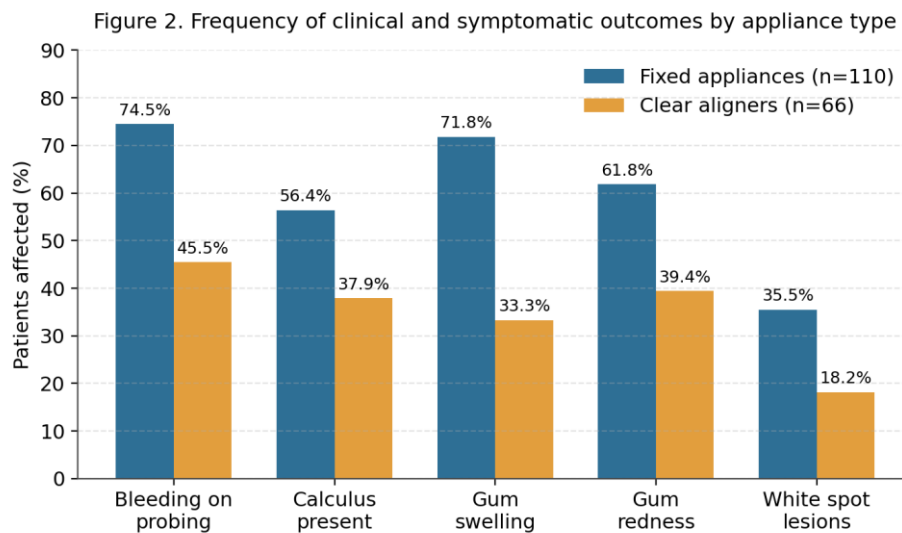


Figure 2. Bar chart comparing the frequency of clinical and symptomatic outcomes (bleeding on probing, calculus, gum swelling, gum redness and white spot lesions) between patients with fixed appliances and clear aligners.

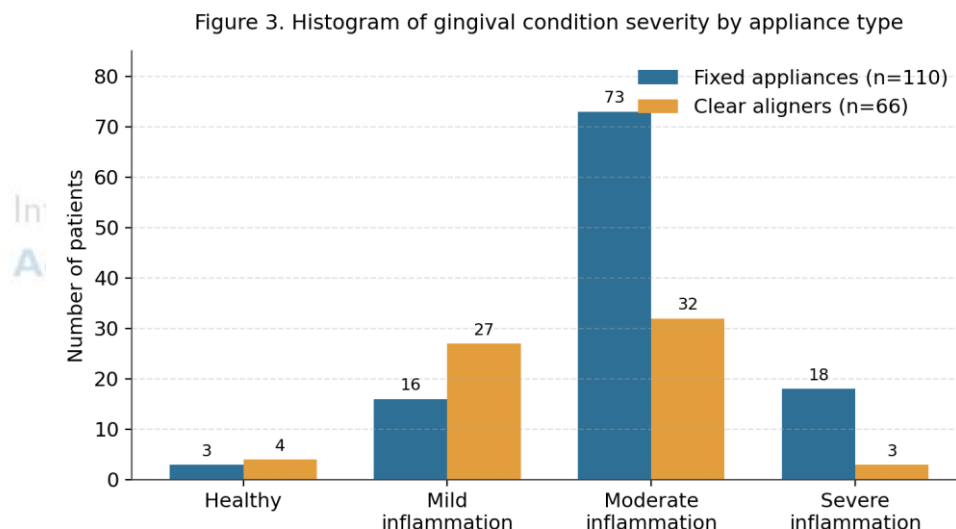


Figure 3. Histogram showing the distribution of gingival condition severity (healthy, mild, moderate, severe inflammation) among patients with fixed appliances and clear aligners.

Figure 4. Overall oral hygiene status of the study sample (N=176)

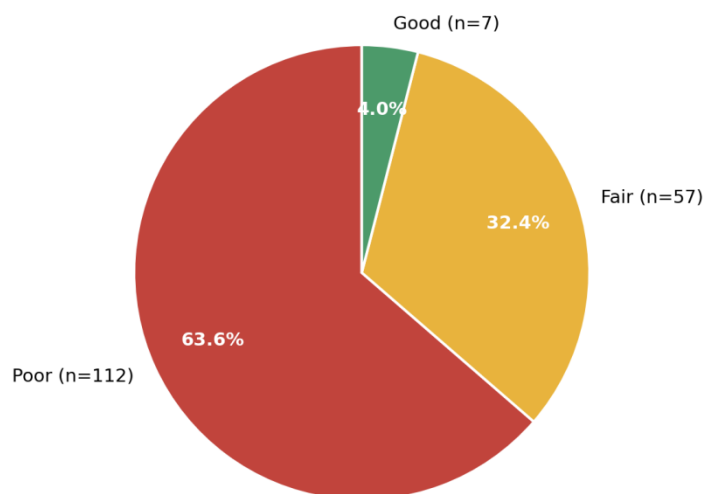


Figure 4. Pie chart showing the overall oral hygiene status (good, fair, poor) of the entire study sample (N=176).

Oral hygiene behaviors and diet

Self-reported oral hygiene behaviors were similar in the two groups (Table 4). About half of participants brushed at least twice daily (50.0% fixed vs. 56.1% aligner; $p=0.633$), and the proportions using dental floss, interdental

brushes, mouthwash and tongue cleaning daily did not differ. Sticky or hard food consumption was more frequent in the fixed appliance group (22.7% vs. 12.1% frequently; $p=0.028$), whereas sugary snack and beverage intake did not differ significantly.

Table 4. Oral hygiene behaviors and dietary habits by appliance type

Behavior	Fixed (n=110)	Clear aligner (n=66)	p-value
Brushing $\geq$ twice daily	55 (50.0)	37 (56.1)	0.633
Brushing duration $\geq$ 2 minutes	62 (56.4)	42 (63.6)	0.393
Electric or orthodontic toothbrush	61 (55.5)	37 (56.1)	0.949
Daily dental floss	41 (37.3)	26 (39.4)	0.848
Daily interdental brush	37 (33.6)	27 (40.9)	0.704
Daily mouthwash	36 (32.7)	21 (31.8)	0.758
Daily tongue cleaning	46 (41.8)	30 (45.5)	0.865
Sugary snacks $\geq$ once daily	52 (47.3)	38 (57.6)	0.089
Sugary beverages $\geq$ 4 times/week	28 (25.5)	10 (15.2)	0.222
Sticky/hard foods: frequently	25 (22.7)	8 (12.1)	0.028

Data are n (%) for the category shown; p-values compare all response categories.

Multivariable analysis

In multivariable linear regression, clear aligner use remained independently associated with lower plaque index ($\beta=-0.335$, 95% CI -0.513 to -0.157 ; $p<0.001$) and gingival index ($\beta=-0.298$, 95% CI -0.443 to -0.153 ; $p<0.001$) after adjustment for age, sex, treatment duration, brushing frequency, professional cleaning, smoking, flossing, interdental brush use and

hygiene instructions (Table 5). Current smoking was associated with higher plaque index ($\beta=0.252$, $p=0.044$), and having received hygiene instructions with lower gingival index ($\beta=-0.212$, $p=0.004$). The models explained 13.0% and 16.5% of the variance in plaque and gingival index, respectively. Treatment duration was not associated with plaque index (Kruskal-Wallis $p=0.640$) or gingival index ($p=0.466$).

Table 5. Multivariable linear regression of plaque and gingival index

Predictor	Plaque index β (95% CI)	p	Gingival index β (95% CI)	p
Clear aligner (ref: fixed)	-0.335 (-0.513 to -0.157)	<0.001	-0.298 (-0.443 to -0.153)	<0.001
Age (per year)	-0.012 (-0.033 to 0.009)	0.279	0.006 (-0.011 to 0.023)	0.517
Female sex	-0.099 (-0.280 to 0.081)	0.279	-0.127 (-0.274 to 0.021)	0.091
Treatment duration (per category)	-0.005 (-0.087 to 0.076)	0.901	0.029 (-0.038 to 0.095)	0.393
Brushing frequency (per category)	-0.007 (-0.094 to 0.080)	0.876	-0.022 (-0.093 to 0.049)	0.542
Professional cleaning frequency (per category)	0.051 (-0.032 to 0.134)	0.226	0.035 (-0.033 to 0.103)	0.309

Predictor	Plaque index β (95% p CI)	Gingival index β p (95% CI)
Current smoker	0.252 (0.007 to 0.496)	0.029 (-0.171 to 0.228)
Flossing frequency (per category)	0.001 (-0.083 to 0.086)	0.017 (-0.053 to 0.086)
Interdental brush use (per category)	-0.026 (-0.105 to 0.053)	-0.023 (-0.088 to 0.041)
Received hygiene instructions	-0.023 (-0.200 to 0.153)	-0.212 (-0.357 to -0.068)

β = adjusted regression coefficient. Ordinal predictors were entered as ordered categories (linear trend). R^2 = 0.130 (plaque index) and 0.165 (gingival index).

Appliance-specific findings

Among fixed appliance patients, 45 of 110 (40.9%) found cleaning difficult or very difficult, and 91 (82.7%) reported food trapping frequently or sometimes. Among aligner patients, 17 (25.8%) reported wearing aligners for 22 hours or more per day and 34 (51.5%) for 18–21 hours; 52 (78.8%) always removed aligners before eating, and 25 (37.9%) always brushed their teeth before reinsertion, whereas 7 (10.6%) never did. Descriptively, the seven aligner patients who never brushed before reinsertion had the highest mean gingival index (1.61 vs. 1.10 in those who always did), but these subgroups were too small for formal inference.

Discussion

In this comparative cross-sectional study, patients with clear aligners had significantly lower plaque and gingival index scores, less bleeding on probing, less calculus and fewer white spot lesions than patients with fixed appliances. The association with appliance type persisted after adjustment for age, sex, treatment duration and self-reported hygiene behaviors, suggesting that the appliance itself contributes to the observed difference.

The size of the differences (0.36 for plaque index and 0.29 for gingival index) is in line with pooled estimates from published meta-analyses, which reported differences of -0.53 and -0.27 , [3] and -0.44 and -0.23 , [4] in favor of clear aligners.

Our findings therefore support the biologically plausible explanation that fixed brackets, bands and wires create additional retention sites and impede mechanical cleaning, whereas removable aligners allow unobstructed brushing and interdental cleaning.[2,3] This is reinforced by the high proportion of fixed appliance patients who reported difficulty cleaning (40.9%) and frequent food trapping (82.7%). By contrast, probing pocket depth did not differ significantly here, whereas pooled estimates have suggested lower probing depth with aligners.[3,4] Probing depth changes slowly and is influenced by gingival swelling and pseudopockets; some reviewers have also cautioned that evidence for a probing depth advantage is limited or unstable.[3,5] The cross-sectional design and the young age of the sample may also have limited our ability to detect it. Microbiological studies support the proposed mechanism: patients treated with fixed appliances accumulate higher salivary levels of cariogenic organisms and greater subgingival pathogenic bacterial load than those treated with clear aligners,[14,15] consistent with the higher plaque and gingival index scores and greater proportion of white spot lesions observed in our fixed appliance group.

An important observation is that the self-reported hygiene behaviors we measured were closely matched between groups and were not associated with plaque or gingival index in adjusted models, apart from smoking and receipt of hygiene

instructions. This means the between-group difference is unlikely to be explained by these behaviors, but it also implies that coarse, self-reported categories (e.g., “brushing twice daily”) may not capture the quality of cleaning; the lack of association with observed plaque should be interpreted cautiously. The association of smoking with higher plaque and of prior hygiene instruction with lower gingival inflammation is consistent with the recognized roles of tobacco use and patient education in periodontal health. Fixed appliance patients were reviewed much more often (70.0% every 2–4 weeks vs. 13.6%), yet had poorer indices, indicating that frequent visits alone do not offset the plaque-retentive nature of the appliance. Treatment duration was unrelated to the indices, which suggests that the plaque-retentive effect is established early in treatment.

Clinically, the results are concerning for both groups. Nearly two-thirds of participants (63.6%) had poor hygiene status, and only 4.0% had healthy gingiva; even among aligner patients, 47.0% had poor hygiene and 53.0% had moderate or severe gingival inflammation. Only about 38% of aligner patients always brushed before reinserting their aligners, and just over a quarter wore them for 22 hours or more, showing that aligner treatment is not automatically protective if hygiene protocols are not followed. Patients with fixed appliances also had more visible white spot lesions (35.5% vs. 18.2%), an early sign of enamel demineralization. Orthodontists should therefore provide appliance-specific instruction, reinforce it at each visit, and consider more frequent professional prophylaxis for patients with fixed appliances.

Strengths and limitations

Strengths include the combination of objective clinical indices with detailed self-reported behaviors and the use of adjusted analysis. Limitations should be acknowledged. First, the cross-sectional design precludes causal inference and does not show change over time, and patients were not randomized to appliance type, so residual confounding by treatment indication,

motivation, case complexity and socioeconomic factors is possible; the aligner group was older and more educated, and appointment intervals differed substantially. Second, hygiene behaviors were self-reported and prone to recall and social-desirability bias, and the regression models explained only a modest proportion of variance. Third, the aligner group was smaller than the fixed group, and appliance-specific subgroup findings were based on small numbers. Fourth, the single-center design and non-probability consecutive sampling limit generalizability, and examination by a single, non-blinded examiner may have introduced assessment bias despite acceptable calibration. Longitudinal studies with baseline periodontal measurements and objective measures of compliance are needed.

Conclusion

Patients treated with clear aligners had significantly lower plaque accumulation and gingival inflammation, less bleeding on probing and calculus, and fewer white spot lesions than those with fixed appliances, independent of age, sex, treatment duration and self-reported hygiene behaviors. Probing pocket depth did not differ significantly. However, oral hygiene was suboptimal in both groups. Structured, appliance-specific oral hygiene education and regular professional cleaning should be an integral part of orthodontic care, with particular attention to patients with fixed appliances.

Declarations

Ethical approval: Institutional Ethical Review Committee, Saidu Group of Teaching Hospital, Swat (approval no. SGTH/ERC/2024-187, dated 10 December 2024).

Informed consent: Written informed consent was obtained from all participants (and parents/guardians of minors) in accordance with institutional ethical guidelines.

Conflict of interest: The authors declare no conflict of interest.

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Author contributions: All authors contributed to the conception and design of the study, data

collection, analysis and interpretation of results, and drafting and critical revision of the manuscript. All authors approved the final version for submission.

Data availability: The data supporting this study are available from the corresponding author on reasonable request.

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