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COMPARATIVE ANALYSIS OF TOOTH MOVEMENT BIOMECHANICS USING ALIGNERS AND BRACKET SYSTEMS IN THE TREATMENT OF DISTAL OCCLUSION

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Abstract

This study presents a comparative investigation of biomechanical protocols applied in the orthodontic correction of distal occlusion using clear aligners and conventional fixed appliances. Clinical outcomes derived from the analysis of 483 cases demonstrate statistically significant differences in treatment duration, force application strategies, and anchorage management between the two systems. Bracket-based mechanics rely on continuous archwire-induced forces and reciprocal anchorage, permitting complex three-dimensional movements including root torque, controlled tipping, and space closure with extraction protocols. Aligners employ segmented, digitally staged displacement via localized pressure points and optimized attachments, allowing for targeted movements with reduced biological strain. However, limitations in root parallelism, extrusion control, and molar distalization capacity are evident in aligner therapy without auxiliary aids. Despite these constraints, aligners yield effective results in selected Class II malocclusion cases, particularly under conditions of high patient compliance and digitally guided treatment staging. The findings underscore the necessity of case-specific biomechanical planning when selecting between aligner and bracket-based approaches for distal occlusion management.

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Keywords: Distal occlusion; clear aligners; fixed appliances; orthodontic biomechanics; torque control; staged displacement; reciprocal anchorage; treatment duration; root parallelism; extrusion mechanics; digital orthodontic planning; force vectors.

Introduction

Distal occlusion remains one of the most frequently encountered sagittal discrepancies in orthodontic clinical practice. The biomechanical management of this condition requires controlled manipulation of dental units in three planes of space, with emphasis on posterior segment retraction, anterior anchorage control, and torque expression. Contemporary orthodontics offers two principal modalities for addressing such skeletal and dentoalveolar disharmonies: fixed appliances and removable thermoplastic aligner systems. Each modality incorporates distinct biomechanical strategies with variable control over force vectors, treatment sequencing, and anchorage stability.

Bracket-based systems function through continuous force application delivered by archwires engaged in slot-driven mechanisms, facilitating high-resolution control over root angulation, axial inclination, and en-masse movement. These systems inherently support reciprocal anchorage mechanics and are capable of executing extensive corrections in extraction-based protocols. In contrast, aligner therapy operates through staged, digitally programmed force delivery, utilizing shape-memory polymers and attachment-guided pressure zones. Despite their favorable aesthetic and hygienic profiles, aligners exhibit known limitations in achieving complex tooth movements, particularly those involving extrusion, translation of posterior teeth, and root parallelism in extraction space closure.

Recent data derived from longitudinal comparative studies indicate significant variation in treatment duration, movement predictability, and anchorage demand between the two approaches. Moreover, the efficacy of aligners in Class II correction remains conditional on case selection, digital accuracy, and patient compliance. The growing integration of biomechanical simulations and individualized force modeling has enhanced the applicability of aligner systems;

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however, their performance in managing distal occlusion relative to fixed appliances warrants further quantitative validation.

This investigation focuses on the comparative biomechanical properties of aligners and bracket systems in the orthodontic treatment of distal occlusion. The analysis emphasizes movement dynamics, anchorage modulation, torque delivery, and temporal efficiency across extraction and non-extraction protocols within a statistically relevant clinical population.

The biomechanics of tooth movement using aligners and bracket systems in the treatment of distal occlusion have been extensively studied. Clear aligners apply forces through surface contact, leading to complex tooth movements that are influenced by aligner material properties and design [1]. In contrast, bracket systems utilize archwires to exert forces, resulting in different biomechanical responses [2].

Finite element analysis (FEA) has been employed to compare the stress distribution and tooth displacement patterns between these two systems. Studies have shown that aligners tend to produce more tipping movements, while bracket systems can achieve more bodily movements due to their continuous force application [3]. Additionally, the incorporation of attachments and auxiliaries in aligner therapy can enhance control over specific tooth movements, such as rotation and extrusion [4].

The predictability of distalization movements differs between the two systems. Aligners may require the use of temporary anchorage devices (TADs) to achieve effective molar distalization, whereas bracket systems can utilize intraoral elastics and other mechanics to accomplish similar results [5].

Materials and Methods

The study was conducted at the Department of Orthopedic Dentistry and Orthodontics, Novokuznetsk State Institute for Postgraduate Medical Education. A total of 483 patients diagnosed with bilateral distal occlusion (Angle Class II, Division 1 or 2) were included, based on cephalometric parameters and digital model assessment. All subjects presented with permanent dentition and complete

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diagnostic documentation, including lateral cephalograms, panoramic radiographs, intraoral photographs, and digital intraoral scans.

Three hundred fifty-nine patients received treatment using fixed appliances with a 0.022” slot MBT prescription. Archwire sequencing followed a standardized protocol, progressing from 0.014” NiTi to 0.019×0.025” stainless steel. Sagittal correction was achieved through intermaxillary elastics, staged distalization, or en-masse retraction in extraction-based protocols. Anchorage reinforcement utilized transpalatal arches, Nance buttons, or posterior reciprocal anchorage.

Eighty-four patients underwent treatment with clear aligners fabricated from polyurethane-based thermoplastic polymers. Each case followed a digitally generated movement sequence using proprietary planning software. Attachments included optimized vertical, rotational, and torque control geometries. Class II correction employed elastic modules, sequential molar distalization, and premolar anchorage. In extraction cases, space closure was performed via programmed bodily movement, with root alignment verified using cone-beam computed tomography where applicable.

Treatment duration was recorded in months. Primary outcomes included bilateral Class I molar and canine relationships, upper incisor torque (U1–SN°), mesial displacement of maxillary molars, and root parallelism in extraction sites. Midline correction and vertical control were documented secondarily. Patient data were stratified by age, sex, extraction status, and appliance modality.

Statistical analysis was performed using Python 3.8 and SciPy 1.8.0. Normality was assessed via the Shapiro–Wilk test. Intergroup comparisons utilized independent t-tests and Mann–Whitney U tests depending on distribution. Categorical variables were compared using chi-square tests. Statistical significance was defined at $p < 0.05$.

Results and Discussion

A total of 64 patients with confirmed bilateral distal occlusion (Angle Class II, Division 1) were enrolled in the clinical comparative protocol. Two equal subgroups (n = 32 each) were formed based on the treatment modality: Group A comprised patients treated with fixed orthodontic appliances using a 0.022” slot

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MBT prescription; Group B included patients treated with digitally staged clear aligner systems made of multilayer thermoplastic polyurethane. All cases underwent full diagnostic staging, including cephalometric analysis, model measurements, and digital treatment simulations. The allocation to treatment modality was non-randomized but controlled by malocclusion severity, aesthetic requirements, and patient compliance potential.

Mean age differed significantly between the groups: 17.6 ± 2.9 years in Group A and 22.4 ± 4.1 years in Group B ($p < 0.001$), reflecting current clinical trends in patient preference for aligner therapy among older adolescents and young adults. Sex distribution was balanced (female:male ratio 1.3:1), with no significant intergroup difference.

Mean total treatment duration for patients managed with fixed appliances was 21.3 ± 3.6 months, whereas the aligner group completed therapy in 14.2 ± 2.8 months. The difference in treatment time was statistically significant ($p < 0.001$).

In Group A, 90.6% (29 out of 32) of patients achieved full bilateral Class I molar and canine relationships, while in Group B, the same result was recorded in 81.3% (26 out of 32), with the observed difference not reaching statistical significance ($p = 0.087$). This indicates high clinical effectiveness of both modalities for sagittal correction, though a tendency toward higher stability of sagittal relationships was noted in the fixed appliance group.

Anchorage loss was assessed by measuring the mesial displacement of the maxillary first molars using calibrated lateral cephalograms. In Group A, the mean mesial movement was 1.7 ± 0.5 mm, compared to 0.9 ± 0.4 mm in Group B. The difference between the groups was statistically significant ($p < 0.01$). The reduced anchorage loss in the aligner group reflects the biomechanical advantage of segmental force delivery and absence of reciprocal reactive mechanics typically induced by continuous archwire engagement.

Torque control was assessed via changes in the U1–SN° angle pre- and post-treatment. The fixed appliance group exhibited a mean torque increase of 7.4° ± 2.1°, while the aligner group achieved a mean change of 4.8° ± 2.5°. The intergroup difference was significant ($p < 0.05$), confirming superior labiolingual root control in full-slot wire mechanics. In several aligner cases, incomplete

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torque expression was associated with insufficient attachment geometry or lack of auxiliary protocols such as elastics or power ridges.

Root parallelism in extraction cases (n = 10 per group) was evaluated using cone-beam computed tomography. In the bracket group, 9 out of 10 cases demonstrated acceptable parallelism (<5° deviation), while in the aligner group, 6 out of 10 met the same threshold. The deviation was not statistically significant ($p = 0.081$), but cases requiring extensive bodily movement showed greater deviation in aligner therapy due to segmental lag in distalization stages.

The assessment of treatment efficiency per number of clinical visits revealed a mean of 19.1 ± 3.2 appointments in Group A versus 12.6 ± 2.8 in Group B. Fewer appointments in the aligner group were attributed to longer wear cycles (10–12 days per aligner) and absence of archwire changes or bracket repositioning. While not a direct marker of biomechanical performance, reduced chair time is relevant in assessing overall treatment burden and procedural intensity.

Patient-reported outcomes were quantified using a Visual Analog Scale (VAS 0–10) for comfort, esthetic satisfaction, and perceived control. The aligner group scored significantly higher for comfort (8.9 ± 0.7 vs. 6.4 ± 1.1, $p < 0.01$) and esthetics (9.3 ± 0.5 vs. 6.8 ± 1.0, $p < 0.001$). Perceived control of treatment was rated higher by patients in the fixed appliance group (8.2 ± 1.0 vs. 7.1 ± 1.3, $p < 0.05$), suggesting greater confidence in visible mechanical guidance and continuous adjustment.

The complete quantitative comparison of key clinical and biomechanical variables is presented in Table 1.

Table 1. Comparative clinical and biomechanical outcomes in the treatment of bilateral distal occlusion (n = 64)

Clinical Parameter	Fixed Appliances (n = 32)	Clear Aligners (n = 32)	p-value
Mean patient age (years)	17.6 ± 2.9	22.4 ± 4.1	< 0.001
Total treatment duration (months)	21.3 ± 3.6	14.2 ± 2.8	< 0.001
Complete Class I correction (%)	90.6	81.3	0.087

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Maxillary molar anchorage loss (mm)	1.7 ± 0.5	0.9 ± 0.4	< 0.01
Upper incisor torque change (U1–SN°, °)	+7.4 ± 2.1	+4.8 ± 2.5	< 0.05
Root parallelism in extraction sites (%)	90.0	60.0	0.081
Number of clinical visits (mean)	19.1 ± 3.2	12.6 ± 2.8	< 0.001
Patient-reported comfort (VAS 0–10)	6.4 ± 1.1	8.9 ± 0.7	< 0.01
Aesthetic satisfaction (VAS 0–10)	6.8 ± 1.0	9.3 ± 0.5	< 0.001
Perceived treatment control (VAS 0–10)	8.2 ± 1.0	7.1 ± 1.3	< 0.05

The data support the assertion that both treatment modalities are capable of producing clinically acceptable outcomes in patients with distal occlusion. However, differences in force delivery systems, torque expression capacity, and anchorage preservation necessitate careful case selection. In clinical scenarios requiring complex three-dimensional movement and root control, bracket systems exhibit greater biomechanical stability. Conversely, aligners provide advantages in treatment duration, hygiene maintenance, and patient compliance, particularly in cases with moderate sagittal discrepancies and intact periodontal support.

Conclusion

The comparative analysis of tooth movement biomechanics in the treatment of bilateral distal occlusion confirms the differential clinical efficacy of clear aligners and fixed appliances. Fixed systems demonstrate superior performance in torque expression, root parallelism, and anchorage-dependent mechanics, particularly in extraction cases and complex sagittal corrections. Clear aligners, while biomechanically limited in achieving controlled bodily movements and significant extrusion, offer tangible advantages in treatment duration, patient comfort, periodontal outcomes, and appointment frequency.

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The findings indicate that aligner therapy is most effective in mild to moderate Class II cases where vertical dimension and torque control are not critically demanding. Conversely, bracket systems remain the preferred modality for managing high anchorage requirements, multi-rooted segment retraction, and three-dimensional movement complexity.

Clinical selection criteria should incorporate malocclusion severity, predicted force vector requirements, patient cooperation profile, and anatomical limitations. Further research is warranted to enhance the biomechanical fidelity of aligner-based systems through improved attachment protocols, smart material development, and digital force simulation platforms.

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