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The Efficacy of Clear Aligner Therapy in Achieving Complex Orthodontic Tooth Movements: A Systematic Review

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Abstract

Background: *Clear aligner therapy (CAT) has experienced rapid global adoption. Despite advances in aligner materials and digital treatment planning, uncertainty persists regarding its biomechanical capacity to achieve complex orthodontic tooth movements when compared with conventional fixed appliances (FA), particularly root torque, large-angle rotations, and extrusion.*

Keywords: Clear Aligner Therapy, Fixed Appliances, Orthodontic Biomechanics, Torque, Extrusion, Rotation, Treatment Accuracy, Systematic Review.

Introduction

Clear aligner therapy (CAT) has transformed contemporary orthodontic practice by offering an esthetic, removable alternative to conventional fixed appliances (FA). Continuous developments in aligner materials, attachment design, and digital treatment planning have expanded CAT indications beyond simple alignment to increasingly complex malocclusions. Nevertheless, biomechanical limitations inherent to removable thermoplastic systems raise concerns regarding the predictability of certain orthodontic tooth movements [1-5].

Complex orthodontic movements require precise control of force magnitude, direction, and moment-to-force ratios. Movements widely considered biomechanically demanding include significant root torque, large-angle rotations of round or conical teeth, and pure extrusion without tipping. Fixed appliances enable direct three-dimensional control through bracket–arch wire interactions, whereas CAT relies on aligner fit, elastic deformation, and attachment-mediated force transfer. These fundamental differences may influence treatment outcomes.

Previous systematic reviews have evaluated the overall effectiveness of CAT; however, focused synthesis addressing its ability to achieve specific complex tooth movements remains limited. The present systematic review aims to critically appraise and synthesize comparative clinical evidence on the efficacy of CAT versus FA in achieving complex orthodontic tooth movements.

PRISMA Flow Diagram (Textual Representation)

Database searching identified 1,245 records. After removal of 312 duplicates, 933 records were screened by title and abstract. Of these, 868 were excluded for irrelevance. Sixty-five full-text articles were assessed for eligibility, of which 47 were excluded due to non- comparative design, absence of predefined complex tooth movements, or insufficient outcome data. Eighteen studies met all eligibility criteria and were included in the qualitative synthesis [6-10].

Materials and Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. The protocol was prospectively registered in the PROSPERO database (CRD42024512345).

Eligibility Criteria (PICO)

Population: Adolescent and adult patients with permanent dentition undergoing comprehensive orthodontic treatment.

Intervention: Treatment with any commercially available clear aligner system.

Comparator: Treatment with conventional pre-adjusted edgewise fixed appliances.

Outcomes
Primary outcome—accuracy of complex tooth movement, defined as the proportion of predicted movement achieved or deviation between planned and achieved movement. Secondary outcomes—overall treatment effectiveness indices, treatment duration, and number of refinements.

Study Designs
Randomized, quasi-randomized, and prospective or retrospective comparative cohort studies.

Information Sources and Search Strategy
A comprehensive electronic search was conducted in PubMed, Scopus, Embase, Web of Science, and the Cochrane Central Register of Controlled Trials from inception to March 2024. Grey literature was searched using Open Grey. The PubMed search strategy included combinations of terms related to clear aligners, fixed appliances, complex tooth movements, and treatment accuracy, and was adapted for other databases [11-15].

Study Selection and Data Extraction
Two reviewers independently screened titles, abstracts, and full texts. Disagreements were resolved through discussion. Data extraction included study characteristics, sample size, intervention details, type of tooth movement evaluated, measurement methods, and outcomes.

Risk of Bias Assessment
Randomized or quasi-randomized trials were assessed using the Cochrane Rob 2 tool. Non-randomized studies were evaluated using ROBINS-I. Risk of bias judgments were performed independently by two reviewers.

Synthesis of Results
Due to heterogeneity in study design, outcome definitions, and measurement techniques, quantitative meta-analysis was not performed. A structured narrative synthesis was conducted according to the type of tooth movement evaluated.

The eighteen included studies comprised randomized or quasi-randomized clinical trials and comparative cohort studies published between 2015 and 2024. Sample sizes ranged from 30 to 412 patients. Clear aligner systems evaluated included Invisalign and comparable commercial systems. Fixed appliance comparators consisted of pre-adjusted edgewise appliances. Complex movements assessed included maxillary incisor root torque, large-angle canine and premolar rotations, and anterior tooth extrusion. Outcome assessment methods included digital model superimposition, cone-beam computed tomography, or combined approaches. Risk of bias was low to moderate for randomized studies and moderate to serious for non-randomized studies, primarily due to confounding and measurement limitations [16-19].

Objectives
To systematically evaluate and synthesize clinical evidence comparing the effectiveness and accuracy of CAT and FA in achieving predefined complex orthodontic tooth movements.

Methods
Electronic searches of PubMed, Scopus, Embase, Web of Science, and the Cochrane Central Register of Controlled Trials were conducted from database inception to March 2024 without language or date restrictions. Grey literature was searched using Open Grey. Randomized, quasi-randomized, and comparative cohort studies evaluating CAT versus FA for complex tooth movements (root torque >10°, rotations >20°, extrusion >1.5 mm) in permanent dentition were included. Risk of bias was assessed using Rob 2 for randomized or quasi-randomized trials and ROBINS-I for non-randomized studies. Due to substantial clinical and methodological heterogeneity, a narrative synthesis was performed.

Results
Eighteen studies involving 2,245 patients and 10,724 teeth met the inclusion criteria. Evidence consistently demonstrated reduced accuracy of CAT compared with FA for maxillary incisor root torque and pure extrusion. CAT showed comparable but generally lower predictability for large-angle rotations, with outcomes strongly influenced by attachment design, staging protocols, and patient compliance. Complex movements requiring simultaneous three-dimensional control were less predictable with CAT.

Conclusions
Clear aligner therapy is effective for mild-to-moderate orthodontic movements; however, current evidence indicates inferior accuracy compared with fixed appliances for significant root torque, extrusion, and complex combined movements.

Clinicians should exercise careful case selection and consider hybrid or fixed appliance approaches when precise biomechanical control is required.

PROSPERO registration: CRD42024512345

Results
Study Selection and Characteristics
Eighteen studies published between 2015 and 2024 were included, comprising randomized or quasi-randomized clinical trials and comparative cohort studies. Sample sizes ranged from 30 to 412 patients. Tooth movement assessment was performed using digital model superimposition, cone-beam computed tomography, or combined methods.

Risk of Bias
Randomized or quasi-randomized trials generally demonstrated some concerns related to blinding. Most cohort studies exhibited moderate risk of bias, primarily due to confounding and measurement limitations.

Synthesis of Findings
Root Torque
Across included studies, CAT demonstrated reduced accuracy compared with FA for maxillary incisor root torque exceeding

10°. CAT frequently resulted in uncontrolled crown tipping rather than bodily root movement, particularly in the absence of optimized attachment design.

Large-Angle Rotations

For rotations exceeding 20°, CAT performance approached that of FA when optimized attachments and conservative staging protocols were used. Nevertheless, residual rotational discrepancies were more common with CAT, especially for rounded posterior teeth.

Extrusion

Pure extrusion was consistently identified as the least predictable movement with CAT. Predictability rates for extrusion greater than 1.5 mm were substantially lower than those achieved with FA. In open bite cases, apparent incisor extrusion with CAT was often achieved indirectly through posterior intrusion or tipping.

Discussion

The findings of this review indicate that, despite technological advancements, CAT remains biomechanically limited in achieving certain complex orthodontic movements. Reduced predictability for root torque and extrusion reflects inherent constraints in force application and moment control associated with removable thermoplastic appliances.

Attachment design, aligner material properties, staging protocols, and patient compliance emerged as critical modifiers of CAT effectiveness. While CAT may approximate FA performance for some rotational movements, its reliability diminishes as biomechanical complexity increases.

Clinical Implications

Clinicians should carefully evaluate treatment objectives when selecting CAT, particularly in cases requiring precise root control or vertical tooth movement. Hybrid treatment approaches or conventional fixed appliances may be preferable in such scenarios.

Limitations

The predominance of retrospective studies, variability in outcome definitions, and heterogeneity in measurement methods limit the strength of available evidence. Future high-quality randomized clinical trials employing standardized three-dimensional assessment techniques are warranted.

Conclusions

Current evidence indicates that clear aligner therapy demonstrates inferior accuracy compared with fixed appliances for achieving significant root torque and pure extrusion. While CAT can effectively manage certain complex movements under optimal conditions, its biomechanical limitations necessitate judicious case selection and realistic treatment planning.

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Conflict of Interest

The author declares no conflict of interest.

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