

From Digital Setup to Clinical Reality: Predictability of Individual Tooth Movements with Clear Aligners

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Abstract— Clear aligner therapy has gained widespread acceptance in contemporary dentistry because of its aesthetic appeal, removability, and integration with digital treatment planning. However, the accuracy of virtual treatment simulations does not always translate into the expected clinical outcomes. This narrative review examines the predictability of individual tooth movements with clear aligners and the factors influencing treatment accuracy. Evidence suggests that predictability varies according to the type and magnitude of tooth movement, tooth morphology, biomechanical requirements, appliance characteristics, and patient compliance. While buccolingual tipping and certain alignment movements may be achieved relatively consistently, rotational correction of selected teeth, extrusion, root torque, and some forms of vertical and bodily movement remain challenging. Discrepancies between planned and achieved outcomes have also been reported in intrusion, deep-bite correction, and molar distalization. Appropriate attachment design, interproximal reduction, movement staging, auxiliary mechanics, and clinical monitoring may improve treatment outcomes when selected according to individual treatment requirements. Clinicians should therefore interpret digital treatment setups as planning tools rather than guarantees of the final result. An understanding of movement-specific limitations is essential for setting realistic expectations, refining treatment mechanics, and improving the clinical effectiveness of clear aligner therapy.

Index Terms—Clear aligners; orthodontic tooth movement; predictability; digital treatment planning; orthodontic biomechanics; treatment accuracy.

I. INTRODUCTION

Clear aligner therapy has evolved considerably since the introduction of computer-aided design and manufacturing into orthodontics. Initially used primarily for mild dental irregularities, clear aligners are now employed in the management of a broader range of malocclusions. Their popularity is attributed to their aesthetic appearance, removability, convenience for oral hygiene, and the ability to visualize proposed treatment outcomes through digital setups.^{1,2}

An important advantage of clear aligner therapy is the capacity to simulate sequential tooth movements before treatment begins. Software-based treatment planning enables clinicians to prescribe the desired positions of individual teeth and manufacture a series of appliances intended to achieve those positions progressively. Nevertheless, a digitally generated treatment plan represents a predicted outcome rather than a guaranteed biological response. Clinical tooth movement depends on the interaction between the aligner and the dentition, force application, periodontal and alveolar bone responses, anchorage, and patient adherence to the prescribed wear schedule.^{3,4}

Discrepancies between planned and achieved movements may result in incomplete correction, loss of aligner tracking, prolonged treatment, and the need for refinement aligners or auxiliary appliances. Early clinical investigations identified differences between predicted and achieved tooth positions, while subsequent studies have demonstrated that the magnitude of these discrepancies varies according to the movement being attempted.⁵⁻⁷ (Figure 1)

Predictability should therefore not be interpreted as a single characteristic of a particular aligner system. Rather, it is movement-specific and influenced by tooth morphology, biomechanics, treatment complexity, and the methods used to measure outcomes. This review examines the evidence concerning the predictability of individual tooth movements with clear aligners and discusses its implications for clinical treatment planning.

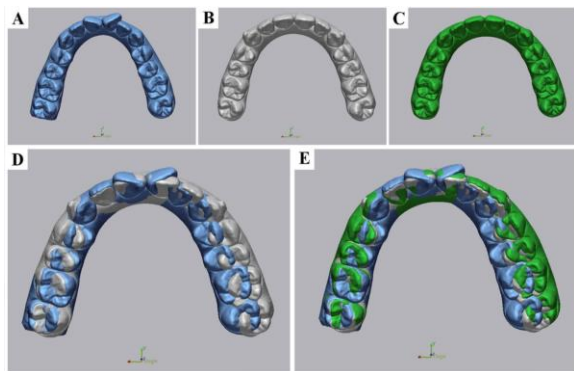


Figure 1. From digital treatment planning to clinical outcomes

II. UNDERSTANDING PREDICTABILITY IN CLEAR ALIGNER THERAPY

Predictability refers to the extent to which the tooth movement achieved clinically corresponds to the movement prescribed in the digital treatment plan. It is commonly evaluated by comparing the planned and achieved tooth positions using digital models, intraoral scans, radiographic records, or three-dimensional superimposition techniques.⁵⁻⁸

A simplified calculation is:

$$\text{Predictability (\%)} = (\text{Achieved movement} \div \text{Planned movement}) \times 100$$

For example, if 2 mm of movement is prescribed digitally and 1.4 mm is achieved clinically, the calculated predictability is 70%.

This calculation is useful for understanding the difference between planned and achieved movement, but its interpretation depends on the measurement method. Linear displacement, angular rotation, crown inclination, and root torque are different outcomes and cannot be compared directly using the same percentage without considering their definitions and measurement protocols.

D'Antò and colleagues evaluated torque, tip, and rotation in 238 maxillary teeth from 17 patients at the end of the fifteenth aligner. Their findings demonstrated that performance varied according to the tooth and movement, emphasizing the importance of evaluating clinical progress rather than assuming that the digital setup will be reproduced exactly.⁸

Similarly, Bilello and colleagues reported that the accuracy of clear aligner treatment varied across different movements and tooth groups. Buccolingual crown tipping was relatively predictable in their study, whereas rotation of certain canines, premolars, and lateral incisors was less reliable.⁹

These findings highlight an important distinction: the successful completion of an aligner sequence does not necessarily indicate that all prescribed movements have been achieved. Clinical assessment must establish whether the actual tooth positions satisfy the intended functional and aesthetic objectives.

III. PREDICTABILITY OF INDIVIDUAL TOOTH MOVEMENTS

1. Tipping and alignment

Tipping involves angular displacement of a tooth in which crown movement exceeds root movement. Clear aligners can produce tipping through contact between the appliance and the clinical crown. Certain tipping movements may be easier to achieve than movements requiring precise root control because the latter demand a more complex force system.

Bilello and colleagues reported that vestibulolingual crown tipping demonstrated high accuracy in their prospective observational study, with approximately 93.1% of the prescribed movement achieved overall.⁹ However, these findings should be interpreted within the context of the particular aligner system, patient population, and measurement method used.

Alignment of mild to moderate dental irregularities is an established application of clear aligner therapy. Nevertheless, improvement in crown alignment does not necessarily indicate complete correction of root position or angulation. Kravitz and colleagues demonstrated discrepancies between predicted and achieved tooth movement in a prospective clinical study, illustrating the limitations of relying exclusively on digital treatment predictions.⁵

Clinicians should therefore distinguish between apparent alignment of the clinical crowns and the

achievement of the complete three-dimensional tooth position. When precise root positioning is required, additional biomechanical control may be necessary.

2. Rotational movement

Rotational correction is one of the movements frequently associated with reduced predictability, particularly for canines and premolars. These teeth may present rounded crown surfaces that provide limited engagement for generating the rotational moment required to produce the prescribed movement. Koletsi and colleagues conducted a systematic review and meta-analysis evaluating rotational tooth movement with aligners. Their findings demonstrated variable rotational accuracy, with the estimated predictability of maxillary canine rotation being approximately 47.9%, compared with a higher estimate for mandibular incisors. The authors also emphasized limitations in the quality and consistency of the available evidence.¹⁰ The prospective study by Bilello and colleagues similarly found that rotational accuracy differed according to tooth type. The overall accuracy for rotation was approximately 86%, but the results ranged from higher values for maxillary central incisors to lower values for mandibular first premolars.⁹ These findings illustrate why results from individual tooth groups should not be generalized to all rotational movements. Attachments may improve aligner engagement and facilitate the application of rotational forces. Interproximal reduction may also be indicated when interproximal interference or insufficient space limits correction. However, neither intervention guarantees complete rotation. The amount of prescribed rotation, crown morphology, aligner fit, and treatment staging remain important considerations.

Clinically, rotational discrepancies should be identified during treatment monitoring. Persistent under-expression may require revised staging, additional aligners, or modified mechanics rather than simply continuing the original sequence.

3. Intrusion

Intrusion requires apically directed tooth movement and appropriate control of the accompanying force system. Its predictability depends on the magnitude of the prescribed movement, anchorage, aligner adaptation, and the response of the surrounding periodontal tissues.

Bilello and colleagues reported relatively high predictability for anterior intrusion in their prospective observational study, with mean predictability of approximately 92% in the teeth evaluated. However, the findings were limited to anterior teeth and should not be generalized to every intrusive movement or clinical situation.⁹

In contrast, research investigating deep-bite correction has demonstrated substantial discrepancies between planned and achieved vertical changes. Shahabuddin and colleagues evaluated 24 patients treated with clear aligners and reported that approximately 33% of the planned overbite correction was achieved after the initial series of aligners. Their study also identified differences between planned and achieved vertical movement and inclination changes across the assessed teeth.¹¹ The apparent differences between these studies emphasize the importance of distinguishing isolated tooth intrusion from correction of an overall deep bite. Deep-bite correction may involve a combination of intrusion, extrusion, inclination changes, and occlusal adjustments rather than a single movement.

Clinicians should therefore evaluate the intended mechanism of correction before selecting the appliance protocol. Where substantial vertical correction or precise root control is required, attachments, modified staging, or auxiliary mechanics may be necessary.

4. Extrusion

Extrusion is often considered biomechanically challenging for clear aligners because the appliance must maintain effective engagement with the tooth while applying a force directed away from the alveolar socket. The effectiveness of this mechanism depends on the shape of the clinical crown, aligner retention, attachment design, and the prescribed movement.

Systematic evidence on clear aligner effectiveness has identified variation in the predictability of vertical movements and emphasized the need to interpret outcomes according to the movement and clinical setting.^{3,12} Extrusion should not be assumed to be predictable merely because a virtual setup shows the tooth moving into the desired position.

Attachments may assist force application, while elastics or other auxiliary mechanics may be considered when aligner-generated forces are insufficient. The choice of auxiliary should be based on the specific clinical objective and the associated

biomechanical requirements. Clinical monitoring should assess aligner seating, attachment integrity, the position of the extruded tooth, and changes in the occlusion. If the prescribed movement is not occurring, the treatment mechanics should be reassessed before further aligners are introduced.

5. Torque and bodily movement

Torque refers to control of a tooth's buccolingual or labiolingual root inclination, while bodily movement requires the crown and root to move in a coordinated direction. Both movements demand effective control of the force system and adequate engagement between the aligner and the tooth. Clear aligners primarily interact with the clinical crown, which can make precise root control challenging. A change in crown position may occur without equivalent root movement, particularly when the prescribed movement requires substantial torque or bodily displacement.

Krieger and colleagues investigated whether anterior tooth movements predicted by Invisalign were achieved clinically and demonstrated discrepancies between predicted and actual outcomes.⁶ D'Antò and colleagues subsequently examined torque, tip, and rotation and found that the accuracy varied according to the specific movement and tooth assessed.⁸ These findings indicate that crown alignment should not automatically be interpreted as successful root control. When root position is critical to the treatment objective, clinicians should assess the achieved position using appropriate clinical records and consider supplementary mechanics when necessary.

6. Transverse expansion

Clear aligners can be used to correct selected transverse discrepancies, particularly those involving dentoalveolar changes. However, an increase in dental arch width does not necessarily represent bodily movement of the teeth or skeletal expansion. The biomechanical response may include buccal crown tipping rather than the intended bodily displacement. This distinction is clinically important because excessive dental inclination may affect periodontal support and compromise the quality of the final result. The scoping review by Muro and colleagues identified variability in the evidence concerning the effectiveness and predictability of clear aligner treatment, including differences across individual movements and expansion outcomes.¹²

Consequently, expansion should be planned according to the nature of the transverse discrepancy, the patient's growth status, and the required magnitude of correction. Where substantial skeletal expansion is indicated, clear aligners alone should not be assumed to provide the required skeletal effect. The appropriate treatment approach should be selected after comprehensive diagnosis and assessment of the periodontal and skeletal limitations.

7. Mesiodistal movement and molar distalization

Mesiodistal movement of posterior teeth depends on anchorage, the amount of prescribed displacement, movement staging, and the control of unwanted movement in adjacent teeth. Molar distalization is commonly incorporated into clear aligner treatment plans, but the actual movement may differ from the digitally prescribed position.

Ravera and colleagues evaluated maxillary molar distalization with aligners in adult patients and demonstrated that distalization can be achieved clinically under selected conditions.¹³ Nevertheless, the extent of movement and the associated tooth inclination must be considered when interpreting these findings.

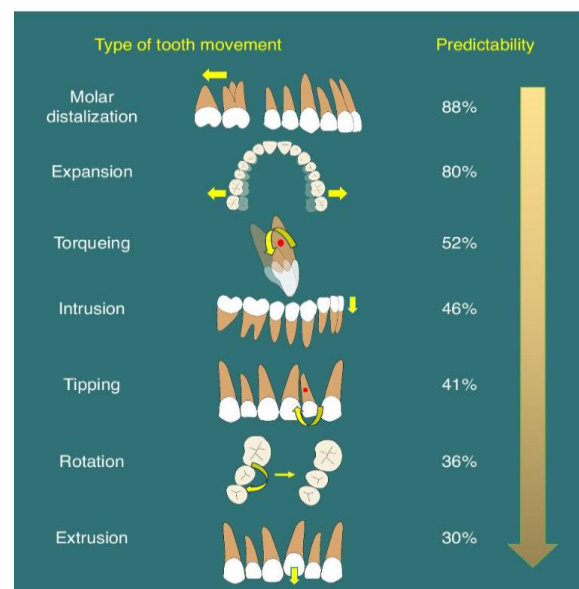


Figure 2. Movement-specific predictability of clear aligners

A systematic review by García-Marín and colleagues examined the predictability of mesiodistal movement of upper and lower molars with clear aligners in the

absence of auxiliary assistance. The review reported approximately 61.1% predictability for upper molar distalization, while findings for lower molars varied. The authors also highlighted limitations in study quality and the certainty of the available evidence.¹⁴ These findings support careful treatment planning for posterior tooth movement. Staging, attachment selection, anchorage control, and auxiliary mechanics may be important when substantial displacement is required. The final assessment should consider not only crown position but also inclination, anchorage, and the intended occlusal relationship. (Figure 2)

IV. FACTORS INFLUENCING PREDICTABILITY

1. Tooth morphology and movement magnitude

Tooth morphology affects the interaction between the aligner and the clinical crown. Rounded crown surfaces may provide less effective engagement for rotation, while movements requiring root control demand more complex biomechanics. The magnitude and direction of movement also influence predictability. Large movements or several demanding movements programmed simultaneously may be more difficult to express than limited, well-controlled movements. Treatment planning should account for these differences rather than assuming uniform accuracy across the dentition.^{9,10}

2. Attachments and auxiliary mechanics

Attachments provide additional surfaces for aligner engagement and may improve the application of selected forces. Attachments may be 3 types: Conventional, Customised, Optimised. (Figure 3) Their effectiveness depends on their shape, position, orientation, and relationship to the planned movement. Auxiliary mechanics, including elastics, buttons, temporary anchorage devices, and limited fixed appliances, may be useful when aligner-generated forces cannot provide the necessary control. However, the presence of attachments or auxiliaries does not guarantee that the prescribed movement will be achieved.

The evidence should therefore be interpreted in relation to the particular movement, the clinical indication, and the appliance protocol rather than assuming that one attachment design is optimal for every situation.

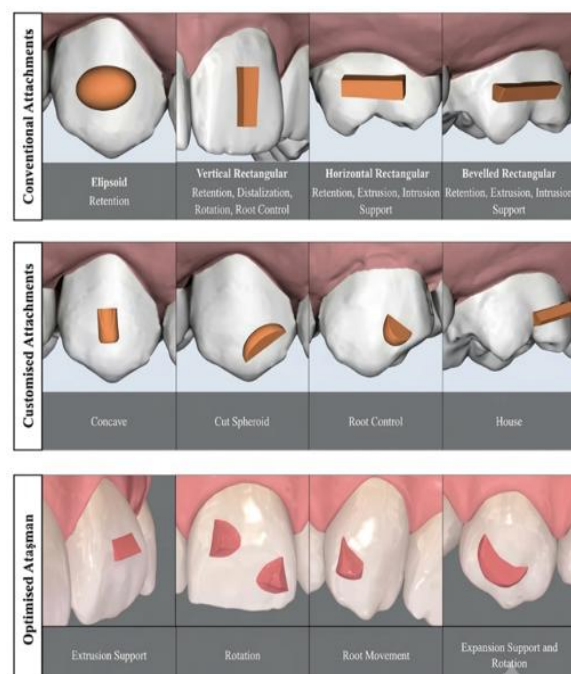


Figure 3. Attachments as a factor influencing the accuracy of clear aligner treatment

3. Interproximal reduction

Interproximal reduction (IPR) creates space between selected teeth and may facilitate alignment, reduce interproximal interference, and assist correction of certain rotations. Its indication depends on the available space, tooth-size relationships, the nature of crowding, and the planned tooth movement. IPR does not independently overcome every biomechanical limitation of clear aligner therapy. It should be performed only when clinically indicated and incorporated into a comprehensive treatment plan.

4. Aligner material and appliance fit

Aligner materials differ in their mechanical characteristics, including stiffness, stress relaxation, and force delivery over time. Appliance thickness, design, manufacturing characteristics, and adaptation to the dentition may also influence performance. Although technological advances have expanded the applications of clear aligner therapy, material improvements do not eliminate biological variability or the need for appropriate biomechanics. Findings obtained using one aligner system should not automatically be generalized to all commercially available systems.

5. Patient compliance

Clear aligners are removable appliances, making treatment outcomes dependent on patient adherence to the prescribed wear schedule. Inconsistent wear, incomplete seating, loss or damage of appliances, and premature progression to subsequent aligners may contribute to loss of tracking. Patient education should emphasize consistent wear, appropriate insertion and removal, and timely reporting of problems. Compliance should be evaluated alongside biological and mechanical factors rather than regarded as the sole explanation for incomplete movement.

6. Treatment complexity and clinical monitoring

Treatment complexity influences the likelihood of achieving the planned outcome without additional aligners or auxiliary mechanics. Cases requiring substantial vertical correction, difficult rotations, extraction-space closure, or extensive root control warrant particularly careful monitoring.

Regular clinical assessment allows discrepancies to be identified before they compromise subsequent stages. Evaluation should include aligner fit, attachment integrity, tooth position, occlusal relationships, and the periodontal condition. When clinical progress differs from the prescribed movement, treatment should be reassessed rather than continued automatically.

V. STRATEGIES TO IMPROVE PREDICTABILITY

Improving predictability begins with accurate diagnosis, realistic digital treatment planning and a proper aligner workflow. (Figure 4) The clinician should identify the specific movements required and determine whether clear aligners can reasonably provide the necessary biomechanical control.

Movement staging should avoid placing excessive demands on individual teeth. Attachments and IPR should be prescribed according to their indications, and auxiliary mechanics should be considered when the required movement exceeds the expected capabilities of the aligner system. Selective overcorrection may be considered for movements known to be incompletely expressed. However, overcorrection should be individualized because excessive programmed movement may produce unwanted effects or compromise aligner tracking.

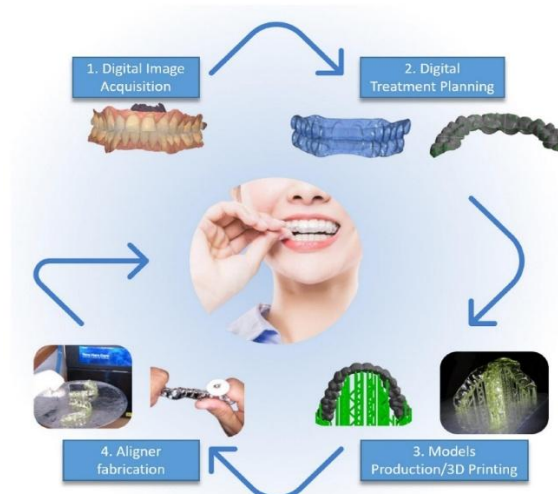


Figure 4. Aligner therapy workflow

Clinical monitoring remains essential throughout treatment. If an aligner no longer fits as intended, the cause should be investigated before progressing to the next appliance. Depending on the findings, management may include additional wear of the current aligner, correction of attachment problems, revised staging, new digital scans, refinement aligners, or supplementary mechanics. Refinement should not automatically be interpreted as treatment failure. It may be an appropriate response to differences between the planned movement and the biological response. Nevertheless, repeated refinements without identifying the underlying cause may prolong treatment and reduce efficiency.

VI. LIMITATIONS OF THE AVAILABLE EVIDENCE

The evidence on clear aligner predictability includes prospective clinical studies, retrospective analyses, systematic reviews, and scoping reviews. Comparisons between studies are complicated by differences in sample size, malocclusion severity, aligner systems, prescribed movements, attachment protocols, patient compliance, and treatment duration.¹¹⁻¹⁴

Measurement methods also vary. Some studies assess linear displacement, whereas others evaluate angular changes or use three-dimensional superimposition. The selected reference points, landmarks, and follow-up intervals can influence the estimated accuracy. Consequently, percentages reported by individual

studies should not be interpreted as universal values applicable to every patient. The evidence is also limited by the predominance of observational designs, variation in study quality, and incomplete standardization of outcome measurements. Studies evaluating specific aligner systems may not be directly transferable to other products or treatment protocols.¹⁵⁻²⁰

Future research should prioritize prospective studies with standardized definitions of planned and achieved movement, transparent reporting of measurement methods, and clinically meaningful outcomes. Research should also distinguish crown movement from root movement and examine the influence of patient characteristics, attachment design, material properties, and treatment complexity on predictability.

VII. CLINICAL IMPLICATIONS

For clinical practice, clear aligner therapy should be planned according to the individual movements required rather than the apparent precision of the digital setup. Clinicians should explain that the virtual treatment plan represents a proposed outcome and that additional aligners or auxiliary mechanics may be necessary. Movements requiring precise root control, difficult rotations, substantial vertical correction, or considerable molar displacement warrant particular attention. Treatment progress should be assessed using clinical examination and appropriate digital records, with modifications introduced when the achieved movement differs from the intended result. Clear aligners can provide effective treatment for appropriately selected patients and malocclusions. Their successful use depends on understanding biomechanical limitations, selecting suitable cases, ensuring patient adherence, and responding promptly when planned movements are not fully expressed.

VIII. CONCLUSION

The predictability of tooth movement with clear aligners is movement-specific and influenced by biological, mechanical, material-related, and patient-related factors. Although clear aligners can effectively achieve many orthodontic corrections, rotational correction of selected teeth, extrusion, precise torque control, certain forms of vertical correction, and substantial molar movement remain challenging.

Digital treatment planning should therefore guide rather than dictate clinical decision-making. Realistic treatment objectives, appropriate attachments and auxiliary mechanics, patient compliance, and regular clinical monitoring are essential for improving treatment accuracy and achieving clinically acceptable outcomes.

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