# Predictability of Rotational Tooth Movement with Clear Aligners and Its Determining Factors: Exploratory Systematic Review

# Predictibilidad del movimiento rotacional dental con alineadores transparentes y sus factores determinantes: Revisión sistemática exploratoria

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## ABSTRACT

**Introduction:**
Clear aligners have become a widely used therapeutic alternative in orthodontics due to their aesthetic and comfort advantages. However, despite advances in thermoplastic materials, three-dimensional digital planning, and attachment design, certain tooth movements continue to present biomechanical limitations. Among these, tooth rotation is recognized as one of the least predictable movements, especially in teeth with unfavorable crown and root morphology, such as canines and premolars.

**Objective:**
To analyze the available scientific evidence on the predictability of rotational tooth movement in patients treated with clear aligners and to identify the main factors that influence the accuracy of this movement.

**Methods:**
An exploratory systematic review was conducted following the PRISMA guidelines. Searches were performed in the PubMed and ScienceDirect databases in English and Spanish, using combinations of MeSH terms and keywords related to clear aligners and tooth rotations.
Original, fully accessible studies published between January 2020 and October 2025 that evaluated the clinical accuracy of rotational movements with aligners were included. Case reports, previous reviews, and studies that included combined treatments with fixed appliances, miniscrews, or orthognathic surgery were excluded.

**Results:**
After the selection process, 10 studies were included for qualitative analysis. The evidence showed that the predictability of rotational movement with clear aligners is variable, with values ranging approximately from 28% to 70%, depending on the tooth type, the magnitude of rotation, and the treatment design.
Incisors showed greater accuracy compared to canines, premolars, and molars, with rotations greater than 10–15° being the least predictable. Factors such as the configuration and type of attachments, treatment staging, the number of aligners, patient compliance, and dental morphology significantly influenced the clinical outcomes.

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**Conclusions:**
Tooth rotation remains one of the least predictable movements in clear aligner therapy. Despite technological advances, the effectiveness of rotational control depends on multiple biomechanical, biological, and digital planning factors. Individualized planning, appropriate use of attachments, and the programming of progressive movements can improve the clinical expression of movement, although the need for refinements remains frequent.

## Introduction

In recent years, clear aligners have revolutionized orthodontic practice by offering an aesthetic, comfortable, and removable alternative to conventional fixed appliances. Their popularity has increased due to advances in digital design, thermoplastic materials, and three-dimensional planning techniques, enabling the treatment of a wide range of malocclusions with increasingly predictable outcomes (Haouili et al., 2020). However, despite technological progress, certain types of tooth movement continue to pose significant biomechanical challenges for aligners (Naoum & Lee, 2025). Among the most difficult movements to control are tooth rotations, particularly in teeth with rounded morphology, such as canines and premolars.

These movements require proper control of frictional forces, effective coupling between the aligner and the tooth surface, and the use of auxiliary attachments to enhance force transmission (Aminian et al., 2024). Several studies have evaluated the overall accuracy of clear aligners by comparing planned versus clinically achieved movements.

Haouili et al. (2020) reported that while aligners are highly effective for movements such as tipping, their accuracy decreases considerably in more complex movements such as rotation and root torque. This variability has driven the need to optimize attachment design and refine clinical protocols to improve biomechanical performance.

Studies such as those by D'Antò et al. (2024) and Castroflorio et al. (2023) have demonstrated that the predictability of these movements varies considerably, with accuracy decreasing when rotations exceed 15 degrees.

Similarly, a recent review by Benedetti et al. (2025) showed that, despite advances in digital design and attachment configurations, the clinical effectiveness of rotational movements remains highly variable across studies.

Recent literature has explored different strategies to optimize rotational control. Fiorillo et al. (2024) evaluated various attachment configurations, reporting greater accuracy when optimized attachments were combined with shorter aligner sequences.

Likewise, studies by Medeiros et al. (2024) and Bilello et al. (2022) have shown that clinical outcomes still differ from digitally planned movements, suggesting that individual biomechanical response and patient adherence remain key determinants of treatment efficacy.

Therefore, the aim of this article is to conduct an exploratory systematic review on the predictability of rotational tooth movement with clear aligners and to identify the factors influencing its accuracy.

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## Materials and Methods

This study was conducted as an exploratory systematic review following PRISMA guidelines to ensure a transparent, reproducible, and structured process.

The research question was formulated according to the PICO format (Table 1): What is the predictability of rotational tooth movement in patients treated with clear aligners, and which factors influence the accuracy of the achieved movement?

**Table 1.** Description of the PICO format

| ELEMENT | DESCRIPTION |
|---|---|
| P (Population) | Patients treated with clear aligners. |
| I (Intervention) | Use of clear aligners for the control of tooth rotations. |
| C (Comparison) | Digitally planned movements vs. clinically achieved movements. |
| O (Outcome) | Predictability and accuracy of rotational tooth movement. |

Searches were conducted in English and Spanish in the PubMed and ScienceDirect databases using a combination of MeSH terms and keywords related to clear aligners and tooth rotation, combined with Boolean operators (AND, OR) (Table 2). The search was limited to full-text articles published between January 2020 and October 2025.

**Table 2.** Bibliographic Search Strategy

| Source | Search Query |
|---|---|
| ScienceDirect | ("clear aligner" OR Invisalign OR ClearCorrect) AND ("tooth rotation" OR "rotational movement") AND (efficacy OR accuracy OR predictability) |
| Pubmed | (("clear aligner" OR "clear aligners" OR "invisible aligner*" OR "transparent aligner*" OR "thermoformed aligner*" OR Invisalign OR ClearCorrect OR Spark) AND ("tooth rotation" OR "rotational movement" OR "rotational control" OR "tooth movement" OR "tooth alignment") AND ("efficacy" OR "accuracy" OR "effectiveness" OR "predictability" OR "treatment outcome" OR "clinical performance")) |

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## Eligibility Criteria

**Inclusion criteria:**

- Original studies (clinical trials, prospective or retrospective studies)
- Publications between 2020 and 2025
- Human studies
- Articles in English or Spanish
- Studies evaluating the predictability, accuracy, or efficacy of rotational movements with clear aligners

**Exclusion criteria:**

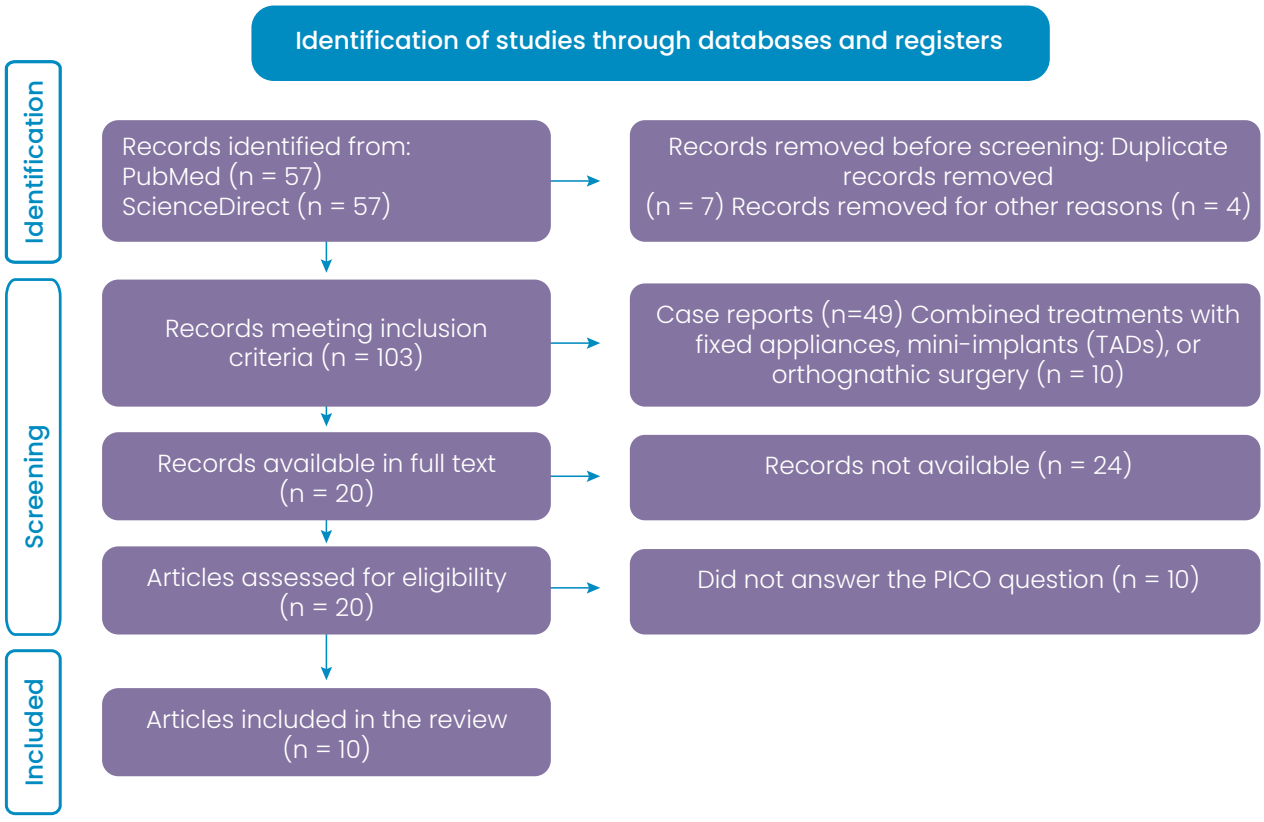
- Case reports
- Literature reviews, systematic reviews, or meta-analyses
- In vitro or animal studies
- Studies involving combined treatments (fixed appliances, miniscrews, or orthognathic surgery)
- Articles without full-text access

**Selection Process**

Identified articles underwent a multi-stage selection process. First, duplicate records were removed. Then, a screening by title and abstract was conducted, excluding studies that did not meet the established criteria. Finally, potentially relevant studies were assessed in full text to confirm eligibility.

The selection process is presented using a PRISMA flow diagram (Figure 1).

**Figure 1.** PRISMA Flow Diagram for the Selection of Studies on Dental Rotations with Clear Aligners

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Due to the heterogeneity of the included studies, no formal risk-of-bias assessment using standardized tools was performed. However, aspects such as study design, sample size, measurement methods, and consistency of results were considered during the qualitative analysis to enable a critical interpretation of the available evidence.

## Results

For this exploratory systematic review on the effectiveness of rotational control with clear aligners, a comprehensive search was conducted in PubMed (n = 57) and ScienceDirect (n = 57), yielding a total of 114 records.

After removing 7 duplicate records and 4 records excluded for other reasons (e.g., incomplete articles), 103 studies met the initial inclusion criteria. During the screening phase, 49 case reports and 10 studies involving combined treatments with fixed appliances, miniscrews, or orthognathic surgery were excluded. Consequently, 44 articles advanced to the full-text assessment stage, of which 24 could not be retrieved due to lack of access.

Finally, 20 articles were evaluated in full text to confirm eligibility, with 10 excluded for not addressing the PICO question. As a result, 10 studies were selected for qualitative analysis and discussion (Figure 1).

A descriptive table summarizing the main characteristics of the included studies was developed, allowing a clear and comparative visualization of their objectives, methodologies, and key findings (Table 3).

**Table 3.** Characteristics of the Included Studies

| Author (year) | Title | Study design | Sample | Intervention | Main results | Influencing factors |
|---|---|---|---|---|---|---|
| Haouili et al. (2020) | The predictability of orthodontic tooth movements through clear aligner among first-premolar extraction patients: a multivariate analysis. | Prospective study | Patients with premolar extractions | Invisalign aligners (SmartTrack, attachments) | Rotations showed low predictability (~46%); tipping was more accurate. | Magnitude >15°, attachments, staging, compliance. |
| Naoum & Lee (2025) | The predictability of tooth movement with clear aligner systems. | Narrative review | Not applicable | Clear aligners | Variable predictability (<30%–85%); rotation and extrusion were less predictable. | Attachments, staging, 20–22 h/day wear, auxiliaries. |
| Desai et al. (2025) | Estimation of centers of rotation of the maxillary incisors during nonextraction space closure using the Invisalign appliance. | Clinical study | Non-extraction patients | Invisalign aligners | Low efficiency (~33%); tipping more predictable; poorer root control. | Aligner biomechanics, tooth morphology, complexity. |

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|---|---|---|---|---|---|---|
| D'Antò et al. (2024) | Predictability of tooth rotations in patients treated with clear aligners. | Clinical study | Patients with aligners | Clear aligners | Moderate predictability (~65–68%); incomplete rotations. | Tooth type, rotation magnitude, attachments. |
| Castroflorio et al. (2023) | Predictability of orthodontic tooth movement with aligners: Effect of treatment design. | Prospective study | Patients treated with Invisalign | Invisalign aligners | Moderate accuracy; rotation and torque less predictable. | Treatment design, staging, dental morphology. |
| Fiorillo et al. (2024) | Accuracy of clear aligners in the orthodontic rotational movement using different attachment configurations. | Clinical study | Patients with different attachments | Aligners with different attachments | Moderate accuracy; 100% rotation not achieved. | Type of attachment, rotation magnitude, biomechanics. |
| Medeiros et al. (2024) | Accuracy of Invisalign® aligners in adult patients: a retrospective study of angular tooth movements. | Retrospective study | Adult patients | Invisalign aligners | Discrepancy between planned and achieved; lower accuracy in posterior teeth. | Dental morphology, planning, adherence. |
| Bilell o et al. (2022) | Accuracy evaluation of orthodontic movements with aligners: A prospective observational study. | Prospective study | Patients with aligners | Clear aligners | Accuracy ~50–60%; rotations less predictable. | Type of movement, usage, magnitude, anchorage. |
| D'Antò et al. (2022) | Evaluation of Tooth Movement Accuracy with Aligners: A Prospective Study. | Prospective study | Patients with aligners | Clear aligners | Simple movements more accurate; limited rotations. | Attachments, staging, compliance. |
| Alwafi et al. (2023) | A new method assessing predicted and achieved mandibular tooth movement in adults treated with clear aligners using CBCT and individual crown superimposition. | Clinical study with CBCT | Adult patients | Aligners + CBCT analysis | Accuracy ~50%; rotations less predictable. | Type of movement, morphology, anchorage, compliance. |

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## Discussion

Recent evidence demonstrates that tooth rotation remains one of the least predictable movements in clear aligner therapy, with reported values ranging between 28% and 70%, depending on tooth type, movement magnitude, and treatment design. Studies by Haouili et al. (2020), D'Antò et al. (2024), Fiorillo et al. (2024), and Medeiros et al. (2024) consistently indicate that canines, premolars, and molars exhibit the lowest rotational accuracy, particularly when movements exceed 10–15°.

Despite technological advances, rotational predictability rarely exceeds 60–70%, often necessitating clinical refinements, overcorrections, or auxiliary approaches (Haouili et al., 2020). Among the factors influencing movement accuracy, tooth type plays a fundamental role. Incisors show greater agreement between planned and achieved movements, whereas canines and premolars present greater difficulty, likely due to their more rounded crown morphology, which limits aligner coupling (D'Antò et al., 2024; Medeiros et al., 2024). Additionally, the magnitude of rotation directly affects predictability, with a significant decrease observed when rotations exceed 15° (D'Antò et al., 2024; Bilello et al., 2022).

Regarding technical factors, attachment configuration and treatment design directly influence rotational control. The use of optimized or rectangular attachments improves force transmission, although it does not fully overcome biomechanical limitations (Fiorillo et al., 2024; Haouili et al., 2020).

Variables such as staging, number of aligners, and progressive distribution of movements have also been shown to be critical in clinical expression (Castroflorio et al., 2023; Alwafi et al., 2023). Short, sequential movement staging appears to enhance accuracy compared to large movements performed in a single step.

Patient-related factors also influence treatment predictability. Compliance with aligner wear, age, and individual biological characteristics such as bone density and periodontal condition can affect the response to tooth movement (Haouili et al., 2020; Medeiros et al., 2024). In particular, adherence to the recommended wear time of 20–22 hours per day is associated with improved clinical outcomes.

From a biomechanical perspective, tooth rotation with aligners is challenging due to the difficulty in generating pure rotational moments. The tendency of the aligner to slip over convex tooth surfaces and the concentration of forces at the crown level favor tipping movements rather than controlled rotations, limiting effectiveness in complex movements (Aminian et al., 2024). This explains why limitations persist despite improvements in materials and digital planning.

The use of three-dimensional evaluation methods, such as digital model superimposition or cone-beam computed tomography (CBCT), has enabled more precise quantification of discrepancies between planned and achieved movements. Studies such as Alwafi et al. (2023) report accuracy values of approximately 50–60%, confirming that rotations and extrusions remain among the least predictable movements.

Overall, the evidence suggests that rotational predictability depends not on a single factor but on the interaction of biomechanical, biological, and digital planning variables. This complexity

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highlights the need for individualized treatment planning, appropriate attachment use, and complementary strategies to optimize clinical outcomes (Haouili et al., 2020; D'Antò et al., 2024; Castroflorio et al., 2023; Fiorillo et al., 2024; Medeiros et al., 2024; Bilello et al., 2022; Alwafi et al., 2023).

Key limitations of the included studies include sample heterogeneity, lack of standardized measurement methods, and small sample sizes. Additionally, limited differentiation among commercial systems restricts the generalizability of findings to broader clinical practice.

Future research should focus on developing standardized evaluation protocols and comparing different materials, aligner designs, and attachment configurations under controlled clinical conditions to improve the predictability and efficiency of rotational movements.

## Conclusion

The analyzed evidence indicates that the predictability of rotational tooth movement with clear aligners remains variable, with better outcomes observed in smaller rotations and in teeth with more favorable morphology.

Despite advances in materials, attachment design, and digital planning, biomechanical limitations affecting movement accuracy persist. The effectiveness of rotational control depends on the interaction of multiple factors, including tooth type, movement magnitude, treatment design, and patient compliance. In this context, individualized planning, appropriate use of attachments, and progressive movement staging are essential to optimize clinical outcomes.

Nevertheless, the need for refinements remains frequent, highlighting that tooth rotation continues to represent a challenge in clear aligner therapy. Further clinical studies with standardized methodologies are required to improve the prediction and efficiency of this type of movement and to strengthen the available evidence.

**Authors contribution statement:**

Conceptualization and design: HNRS, AMM
Literature review: HNRS
Methodology and validation: HNRS, AMM
Formal analysis: HNRS
Research and data collection: HNRS
Resources: HNRS
Data analysis and interpretation: HNRS, AMM
Drafting: HNRS
Writing, revision, and editing: HNRS, AMM
Supervision: AMM
Project management: HNRS

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