Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

COMPARATIVE STUDY OF ROTATIONAL MOVEMENTS OF MANDIBULAR INCISORS WITH CLEAR ALIGNES: PREDICTED VS.ACHIEVED OUTCOMES

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ABSTRACT

Introduction: The transparent aligners have become a widely used treatment option in orthodontics due to their aesthetics and patient comfort. Nonetheless, their predictability on dental movements including rotational movements over mandibular incisors has remained limited and inconsistent across different clinical situations. **Objective:** This study aims to evaluate how closely the predicted rotational movements by numerical softwares match the clinical outcomes obtained at the first refinement phase, as well as to analyze the influence of the initial rotation amplitude and the inter-practitioner variability. **Methodology:** A retrospective study was conducted over 40 patients treated with transparent aligners by two experienced practitioners. Mandibular incisors were classified into three groups according to their initial rotation (<5°, 5–15°, >15°). The correction percentage was calculated for each group. The statistical analyses included an independent sample t-test and an analysis of variance, with a significance threshold set at 0.05. **Results:** A significant decrease in predictability was observed as the initial rotation amplitude increased. Teeth with minor rotations showed higher correction rates compared to those with moderate and severe rotations. Significant differences between practitioners were highlighted for rotations greater than 5°. **Conclusion:** The ability to predict mandibular incisor rotations outcomes depend strongly on their initial amplitude and biomechanical factors. The results highlighted the limitations of current digital planning systems, especially for large rotations, and revealed the need for early clinical adaptations.

KEYWORDS: Dentistry; transparent aligners; dental rotation; predictability; mandibular incisor.

RESUMEN

Introducción: Los alineadores transparentes se han convertido en una opción de tratamiento ampliamente utilizada en ortodoncia debido a su estética y comodidad para el paciente. Sin embargo, su predictibilidad en los movimientos dentales, incluidos los movimientos de rotación de los incisivos mandibulares, ha seguido siendo limitada e inconsistente en diferentes situaciones clínicas. **Objetivo:** Este estudio tiene como objetivo evaluar en qué medida los movimientos de rotación predichos por los softwares numéricos coinciden con los resultados clínicos obtenidos en la primera fase de refinamiento, así como analizar la influencia de la amplitud de rotación inicial y la variabilidad entre profesionales. **Metodología:** Se realizó un estudio retrospectivo sobre 40 pacientes tratados con alineadores transparentes por dos profesionales experimentados. Los incisivos mandibulares fueron clasificados en tres grupos según su rotación inicial (<5°, 5–15°, >15°). Se calculó el porcentaje de corrección para cada grupo. Los análisis estadísticos incluyeron una prueba t para muestras independientes y un análisis de varianza, con un umbral de significación establecido en 0,05. **Resultados:** Se observó una disminución significativa de la predictibilidad a medida que aumentaba la amplitud de rotación inicial. Los dientes con rotaciones leves mostraron tasas de corrección más altas en comparación con los de rotaciones moderadas y severas. Se destacaron diferencias significativas entre los profesionales para rotaciones superiores a 5°. **Conclusión:** La capacidad de predecir los resultados de las rotaciones de los incisivos mandibulares depende en gran medida de su amplitud inicial y de factores biomecánicos. Los resultados pusieron de manifiesto las limitaciones de los sistemas actuales de planificación digital, especialmente para grandes rotaciones, y revelaron la necesidad de adaptaciones clínicas tempranas.

PALABRAS CLAVE: Odontologia; alineadores transparentes; rotación dental; predictibilidad; incisivos mandibulares.

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1. INTRODUCTION

Orthodontics aims to correct the alignment of teeth and jaws to improve function and aesthetics, while preventing disorders related to chewing, speech and joint health (1).

The etiology of orthodontic problems is varied, involving genetic, environmental and behavioral factors. Certain abnormalities, such as narrow jaw or tooth agenesis, are often transmitted (1). Childhood habits also influence orthodontic development and can lead to malocclusions (2). Poor hygiene, improper tongue position or poor swallowing can affect the misalignment of teeth.

1.1. Angle's classification of malocclusion

In 1899, Angle proposed a classification of malocclusions according to the relationship of the first molars, still used today:

Class I: normal molar relationship, but possible crowding or diastema.

Class II: upper molar in front of the lower, often with a convex face.

Class III: upper molar behind the lower.

Dewey then proposed subdivisions to refine diagnosis and treatment (3,4).

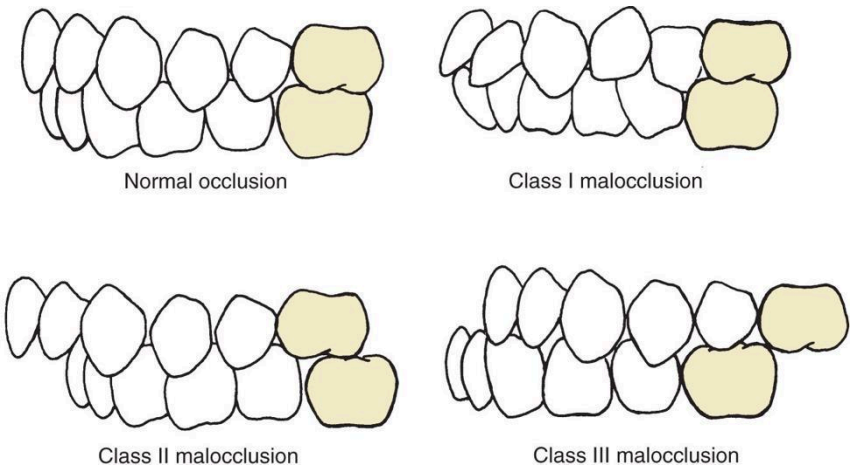


Fig. 1. Normal occlusion and malocclusion classes as specified by Angle (3).

1.2. Evolution of orthodontic treatment

In the 19th century, Angle created the first fixed appliances (E-Ark), ancestors of modern devices. Orthodontics has thus moved from simple mechanical devices to sophisticated digital systems (1,5).

At the beginning of the 20th century, the appearance of new materials allowed more precise dental movements. In the 1970s, stainless steel was replaced by nickel-titanium (Niti), offering better control, more comfort and more predictable results. (6,7).

The evolution of transparent aligners began in 1945 with Keskling, then refined to the modern version of Pontiz in 1971. Initially limited by manufacturing in the laboratory, technological advances have allowed more discreet and effective treatments, sometimes replacing fixed devices. Today, orthodontics integrates intraoral scanners, virtual setups and 3D printing for optimal precision and planning. (1,8). Moreover, incorporation of artificial intelligence has further simplified and improved orthodontics processes (9).

In this technology world, clear aligners have become a significant invention in modern orthodontics. They combine digital accuracy with a clean look to meet the growing demand for orthodontic treatments that are comfortable and can not be seen.

1.3. Types and design of clear aligners

There are different types of clear aligners, such as orthodontic aligners for teeth alignment, aligners used for patients with bruxism, those indicated for temporomandibular joint disorders, and passive aligners used after fixed orthodontic treatment. In this paper, we will focus solely on clear aligners designed for teeth alignment. Their widespread popularity is mainly due to their effectiveness with this type of device, which offers comparable outcomes to those of traditional treatments. Moreover, their discreet appearance has made them particularly popular among adult patients (10).

According to several studies and publications, treatment with clear aligners is as effective as fixed treatment for correcting *Class I* malocclusions. However, it has certain limitations, particularly for complex tooth movements such as rotations or vertical movements (intrusion and extrusion movements) (11).

Among the factors influencing the efficiency of aligners, the properties of the material are decisive: the composition of the polymer and the manufacturing technique play a key role. In 1998, AlignDesign launched the first aligners using CAD/CAM technology and transparent thermoplastic polymers. Since then, several generations of materials such as Exceed30 and SmartTrackTM have improved the accuracy, comfort and predictability of orthodontic treatment (12).

Research shows that the thickness and elasticity of the aligner directly influence the force applied to the teeth. With time and temperature variations, the material loses its strength, which reduces the predictability of the treatment (13).

The addition of composite attachments to aligners, designed by Align Technology, allows for greater control and predictability in dental movement (14,15). The attachments, made of a composite of the color of the teeth, improve the retention of the aligners and allow better control over the type and direction of dental movements. They can be placed on different sides of the teeth (16). As a result, the development of clear aligners has greatly increased their biomechanical effectiveness and broadened their range of therapeutic applications.

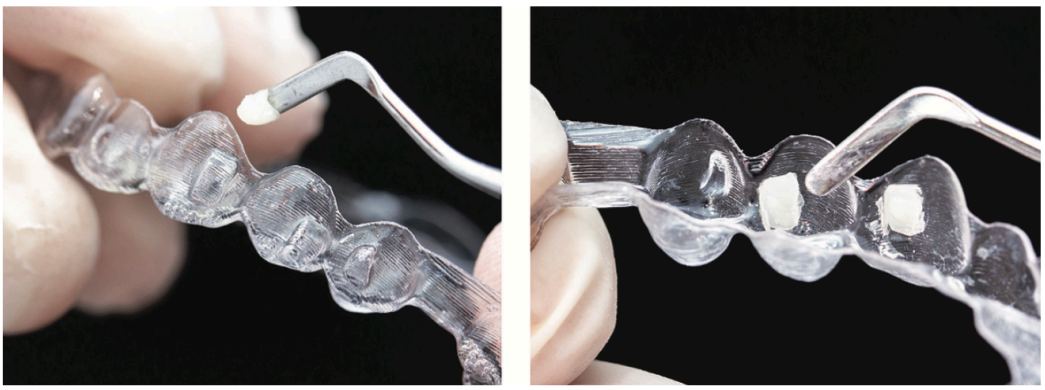


Fig. 2. Placement of composite attachment over a template prior to transfer to teeth (17).

The aligners move the teeth through the elastic deformation of the thermoplastic, generating continuous forces that allow a gradual movement to the desired position.

1.4. Manufacturing process of clear aligners

Today, the manufacturing of aligners begins with an oral impression, performed with an intra-oral scanner or traditional materials, supplemented by photos and X-rays. Two manufacturing circuits exist: a conventional flow based on physical fingerprints and a digital flow using computer-aided design. The treatment planning and the number of aligners are

determined by software, which also models the attachments. The aligners are then produced by thermoforming or 3D printing from digital models (3,12)

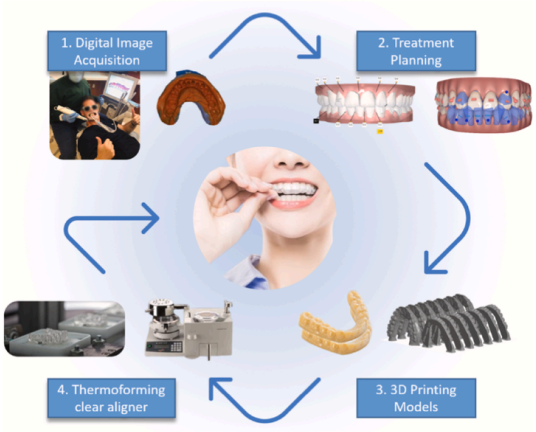


Fig 3. Workflow of fabrication of clear aligners by the thermoforming process (12)

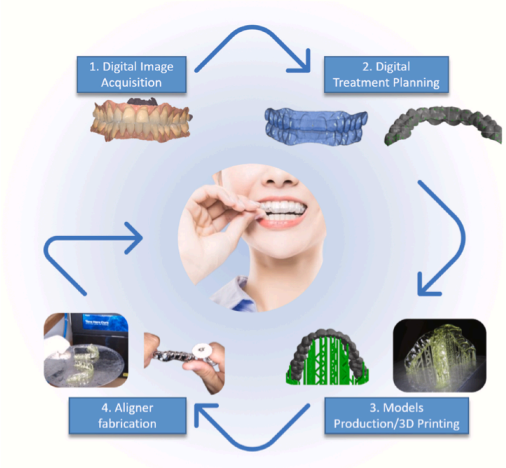


Fig 4. Stepwise fabrication process of 3D direct-printed clear aligners (12)

Each aligner differs slightly from the previous one, allowing for controlled and progressive tooth movement. The manufacturing influences might influence the thickness of the aligner, because the thickness of the aligner is directly proportional to the magnitude of the orthodontic forces delivered for tooth movement (16).

1.5. Mode of actions of Aligners

The transparent aligners induce dental movements through a step-wise mechanism, with each aligner applying controlled forces corresponding to a planned phase of treatment. This progression is optimized by digital algorithms determining the movements, the attachments

and the sequencing. However, their effectiveness remains mainly limited to simple movements, with constraints on complex root control (16).

1.6. Type of tooth movement achievable with aligners

Transparent aligners allow dental movements by the application of controlled mechanical forces, inducing bone remodelling at the periodontal ligament.

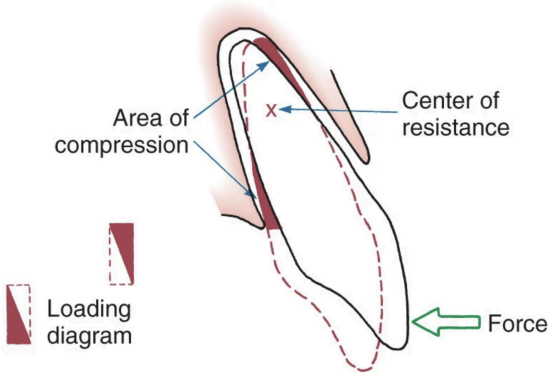


Fig.5. Schematic representation of dental inclination movement. The force applied to the crown creates a compression zone in the periodontal ligament and pivoting around the center of resistance (3)

A light and continuous force causes resorption and bone apposition, allowing the tooth to move with its supporting structures. The effectiveness of the movement depends mainly on the intensity of the force and its distribution within the periodontal ligament, which varies according to the type of displacement sought (3)

The following table summarizes the main types of orthodontic tooth movements, the corresponding distribution of forces within the periodontal ligament, and the optimal force levels required for each.

Type of movement	Description of the tooth movement	Distribution of forces in the PDL	Level and distribution of force required (g)

Tipping	The tooth pivots around its center of resistance; the crown and root move in opposite directions.	Localized compression areas at the alveolar crest and root apex.	35 – 60 g (light to moderate force concentrated at two poles of the PDL).
Bodily movement /Translation	The crown and root move in parallel in the same direction.	Evenly distributed pressure along the entire PDL surface.	70 – 120 g (greater, uniformly distributed force).
Root Uprighting	Correction of an inclined tooth around its apical region.	Apical compression on one side and cervical tension on the opposite side.	50 – 100 g (moderate couple generating root uprighting).
Rotation	Tooth pivots around its long axis.	Asymmetric compression around the root depending on tooth morphology.	35 – 60 g (localized force on opposite proximal surfaces).
Extrusion	Vertical movement of the tooth out of the alveolar socket.	Tension of the coronal fibers of the PDL.	35 – 60 g (light vertically directed force).
Intrusion	Vertical movement of the tooth into the alveolar bone.	Compression concentrated at the apical region of the PDL.	10 – 20 g (very light and precisely directed force).

Table 1 – Distribution of forces in the PDL according to the type of tooth movement and recommended optimal force values (adapted from (3).

1.7. Predictability and accuracy of clear aligners

The main challenge of aligners treatment lies in matching digitally planned movements (ClinCheck®) with clinical results. Predictability and accuracy depend on multiple factors, including biological parameters, mechanical properties, treatment planning and patient

compliance. The dental morphology also plays a decisive role, as teeth with rounded surfaces have less precision, particularly for rotational movements (18).

A prospective study showed limited precision of rotational movements with aligners, reaching 36% for canines, against about 55% for maxillary central incisors and 52% for mandibular lateral incisors. These differences are explained in particular by the conical morphology and the contact surface of the canines, which reduce the effectiveness of the applied forces (19,20)

When considering clear aligner treatment, it is important to keep in mind its limits. Orthodontic tooth movements such as intrusion, extrusion, and rotation are the least accurate movements because they are considered complex and remain unpredictable (23).

Several studies have shown that the use of composite attachments improves the precision of premolar rotational movements by up to approximately 10°. However, other studies have reported contradictory results regarding the derotation movements of canines, even in the presence of attachments. A systematic review published in 2019 concluded that there is a lack of scientific evidence confirming the effectiveness of attachments in improving rotational movements. Nevertheless, it is generally recommended to place attachments on teeth requiring rotations greater than 15° in order to optimize force transmission and movement stability (21).

Staging refers to the sequential planning of dental movements and anchoring areas during treatment. It conditions the controlled progression towards the final position. Any deviation from a step compromises the reliability of subsequent steps and the correspondence between virtual planning and clinical results (22). Despite optimized staging, clinical movements may diverge from those planned, requiring a refining phase. This is based on a new intra-oral scan to assess the discrepancies and adjust the treatment. It allows you to correct incomplete movements, generate new aligners and, if necessary, introduce overcorrections. Refinement is thus an essential step to improve precision and adapt the treatment to real clinical results.

The IPR can be carried out after refinement in order to create space and facilitate residual movements, especially in case of persistent rotations. Patient compliance, with a wear of at least 22 hours per day, is essential to ensure continuous strength and effective treatment. The frequency of changing aligners depends on the complexity of the movements. Other factors,

such as material, thickness and fastenings, also influence accuracy, but have been discussed previously.

1.8. Focus on mandibular incisor rotation

The rotational movements of the mandibular incisors remain complex due to their low coronal surface, radicular morphology and interdental proximity. The aligners act by elastic deformation, generating an initial force that decreases with adaptation to the tooth. However, imperfect adhesion, especially interproximal, limits the transmission of forces, making rotations less predictable. The use of fasteners or power ridges aims to improve mechanical grip, but the reduced surface area of the mandibular incisors results in less stable forces and limited accuracy (23).

According to the scientific study of Antò et al. (2024), report a better rotational precision of the mandibular incisors compared to canines and premolars, due to their less conical morphology. The accuracy rates reach 88.34% for the central incisors and 89.61% for the lateral ones. However, cases of overcorrection are observed, especially for the central incisors, while the lateral incisors show more stable and predictable results (18). Previous studies (Kravitz et al., 2009; Rossini et al., 2015) reported lower accuracies (52–55%), suggesting an improvement related to technological advances, but potentially biased by overcorrections.

Thus, despite notable progress, the precise control of rotations remains limited. A clinical evaluation comparing the numerical predictions and the results after refinement is therefore necessary to determine the actual accuracy and predictability of the aligners treatment.

2. OBJECTIVES

Compare the accuracy and efficiency of planned rotational movements of mandibular incisors with the results obtained before the first refinement is performed.

Evaluate the predictability of rotational movements of mandibular incisors based on the amplitude of the planned rotation, stratifying movements into three categories: small rotations (≤ 5°), moderate rotations (5° to 14°) and large rotations (≥ 15°).

Compare the accuracy and efficiency of rotational movements of mandibular incisors between two practitioners, both registered as specialist orthodontists in the Irish Dental Council, both with over fifteen years of experience in aligners but with different training backgrounds.

2.1. Hypotheses

In accordance with the objectives outlined above, the following hypotheses were formulated

Hypothesis 1: The rotational movements predicted by ClinCheck® software will not fully correspond to the clinical results obtained prior to the first refinement phase, with a significant discrepancy expected between the planned corrections and the corrections actually achieved.

Hypothesis 2: The predictability of rotational correction decreases as the initial degree of rotation increases; teeth with large rotations (≥15°) show significantly lower rates of correction than those with small rotations (≤5°).

Hypothesis 3: No statistically significant differences in rotational correction results will be observed between the two practitioners for small rotations, whereas differences may emerge for moderate and large rotations due to differing clinical strategies and training.

3. MATERIAL AND METHODS

3.1. Study design

The final year project is an empirical, retrospective study based on the analysis of quantitative data from treatments performed by two dentists specializing in orthodontics. The main objective was to evaluate the effectiveness and predictability of lower incisor rotation movements by comparing the results predicted by the first ClinCheck® software (initial simulation) with the movements actually obtained during the refinement phase.

This study was approved by the TFG Committee of the European University of Madrid, approval code: OD.009/2526

3.2. Sample selection

A total of 40 patients were selected between 2016 and 2024: 20 treated by the first practitioner and 20 treated by the second. All patients presented Class I skeletal relationship, class 1 molar relationship with crowding and they presented diverse degrees of lower incisors rotations.

Inclusion criteria: Patients with Class I occlusion, complete permanent dentition, presence of at least one lower incisor requiring rotational correction. Complete files including: pre-treatment digital scans - initial ClinCheck® simulations pre-refinement scans.

Exclusion criteria: Presence of systemic pathologies or conditions likely to influence orthodontic movement, incomplete digital files or files with missing data that do not allow for accurate measurement of movements (missing scans, incomplete ClinCheck®, absence of pre-refinement model), lower incisors without measurable rotational movement.

No experimental intervention was performed. The treatments had been previously performed by two experienced orthodontists. Although they have different backgrounds, both practitioners have more than 15 years of experience with aligners, including Invisalign® both are registered in the specialist list in the Irish Dental Council.

The patients included in this study were treated in private dental clinics. This is a retrospective study based on the analysis of pre-existing clinical records. Patients signed an informed consent form authorizing the use of their clinical data for academic purposes. All data was anonymized prior to analysis, ensuring compliance with confidentiality and data protection principles.

3.3. Classification of rotation

The data was extracted from ClinCheck® software, a digital planning tool used by Invisalign®. The planned rotation values were extracted directly from the ClinCheck® table "Tooth movements" (Initial Setup). The actual rotation values obtained were extracted from the table corresponding to the pre-refinement model (Next scan). The difference between the two stages corresponds to the actual movement achieved.

For each lower incisor involved, the following data was recorded: Expected rotation (in degrees) on the initial simulation and Rotation achieved (in degrees) on the pre-refinement model. Rotations were classified into three categories:

- < 5°: slight
- 5–15°: moderate
- > 15°: severe

3.4. Outcome measurements

The predictability of movements was calculated using the following formula:

Predictability (%) = $(actual\ rotation)/\ (planned\ rotation\ )\ x\ 100$

This percentage allows us to assess the extent to which the clinical movement approximates the ideal standard defined in the digital planning.

The data used comes from existing clinical records and was completely anonymized prior to analysis. No patients were contacted or directly involved. The study complies with confidentiality rules and ethical principles related to the use of retrospective data.

3.5. Statistical analysis

The mean and standard deviation (±SD) of the patients' age and the percentage of correction of mandibular incisor rotation were obtained. The analysis was performed using Student's t-test for independent samples and one-way ANOVA after verifying the homogeneity of variances in both cases using Levene's test. The significance level was set at 0.05 for two tails.

4. RESULTS

As shown in Table 2, mandibular incisors were more frequently distributed in the <5° group (n = 69) and less frequently in the >15° group (n = 36).

Degree of rotation	**Lower Right Lateral Incisor (LR2)**	**Lower Right Central Incisor (LR1)**	**Left Mandibular Central Incisor (LL1)**	**Left Mandibular Lateral Incisor (LL2)**	**Total**
<5°	13	19	16	21	69
5-15°	18	16	13	8	55
>15°	9	5	11	11	36

	40	40	40	40	160

Table 2 - Number of mandibular incisors in each of the groups according to the degree of rotation they initially had before treatment.

Table 3 shows the 40 patients who participated (20 men and 20 women) as well as the mean age in years (29.6±8.4) and that there were no statistically significant differences in age between men and women (t = 1.1041, p = 0.2765).

Variable	**Men**	**Women**	**Total**
Number	20	20	40
Age*	31.05 ± 7.7	28.2 ± 8.6	29.6 ± 8.4
* t Student 1.1041, p = 0.2765			

Table 3- Number of male and female participants and their ages in years with mean ± standard deviation.

Table 4 shows the mean and standard deviation of the percentage correction of the initial degree of rotation after treatment with Invisalign® in each group according to the degree of rotation of the mandibular incisors before treatment. The ANOVA gives a highly significant value (p < 0.001 and F = 49.609), as does Scheffé's post hoc test (p < 0.001, with differences between the three groups). In the group with low initial rotation (<5º), this is corrected by 68.2 ± 10.3%, while in the group with high rotation (>15º), it is corrected by 44.9 ± 10.5%.

Degree of rotation	**Size**	**×±SD**	**F**	**p**
<5°	69	68.2 ± 10.3	49.609	< 0.001
5-15°	55	58.0 ± 13.2		
>15°	36	44.9 ± 10.5		
Test of Scheffé posteriori p < 0.001 between the three groups				

Table 4- Mean percentage of rotational correction (X̄ ± SD) of mandibular incisors according to the initial degree of rotation (<5°, 5-15°, >15°) after treatment with Invisalign® aligners, with one-way ANOVA results.

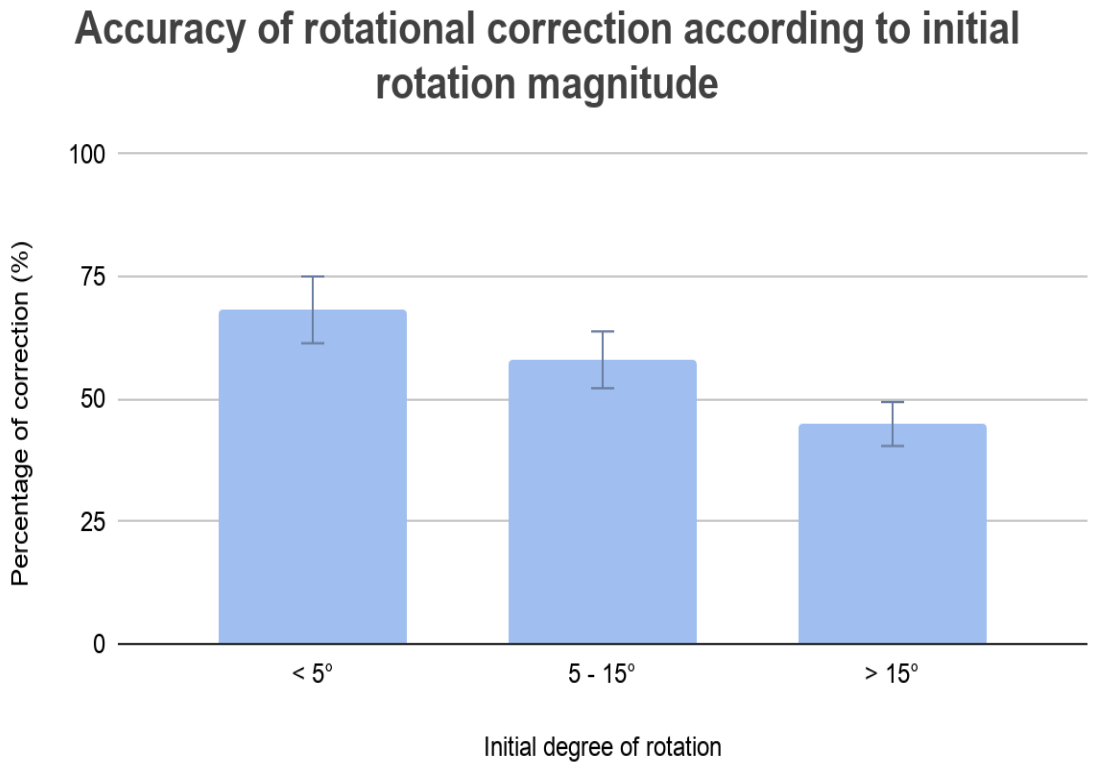


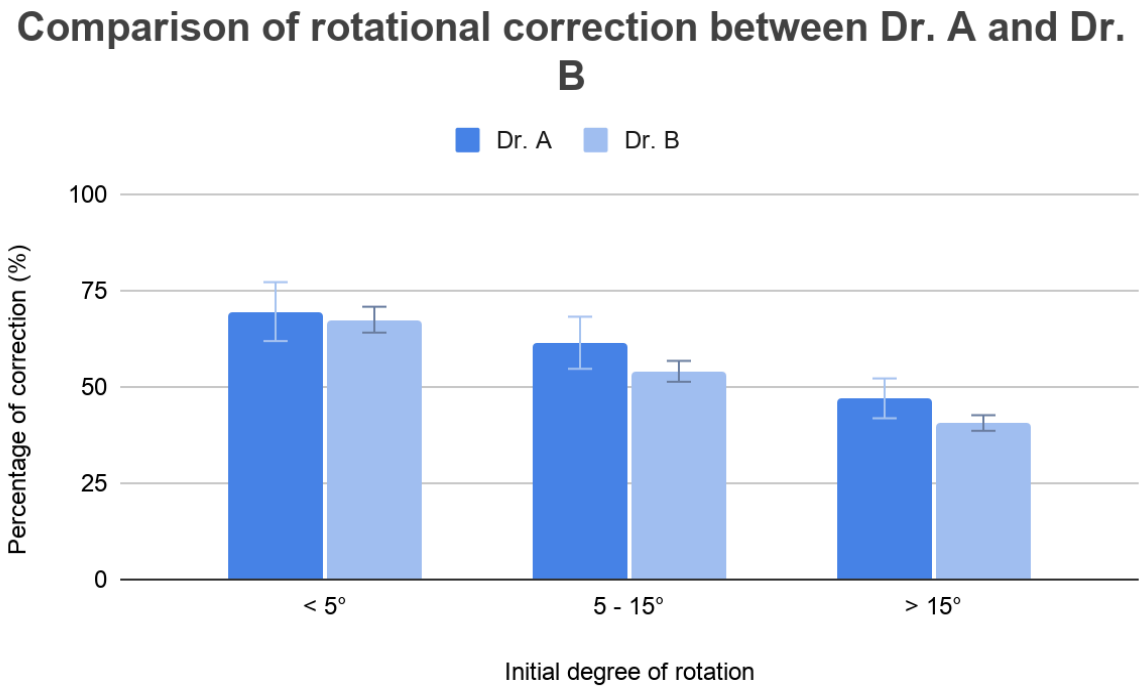
Figure 6: Mean percentage of rotational correction of mandibular incisors according to the initial degree of rotation (<5°, 5–15°, >15°) after treatment with Invisalign® aligners.

Table 5 shows that in the <5º group there are no statistically significant differences between Dr. A and Dr. B (p = 0.411). In the 5–15° group, statistically significant differences were observed between practitioners (t = 2.234; p = 0.030). In the >15° group, significant differences were also found (t = 2.247; p = 0.031).

Degree of rotation	Dr. A		Dr. B			
	Size	X̄±SD	Size	X̄±SD	t	p
<5°	26	69.5 ±11, 1	43	67.4 ±9,9	0.826	0.411
5-15°	30	61.4 ±15,	25	54.0 ±8,9	2.234	**0.030**

		4				
>15°	24	47.0 ±11, 7	12	40.6 ±5,5	2.24 7	**0.03 1**

Table 5 - Comparison of the percentage of correction according to rotation between Dr. A's group and Dr.



B's group.

Figure 7: Comparison of the mean percentage of rotational correction of mandibular incisors between Dr. A and Dr. B according to the initial degree of rotation.

5. DISCUSSION

Clinically, we can see in Table 1, that the mandibular incisors do not require a large degree of derotation, indeed severe rotations are less frequent. The mandibular incisors often present slight rotations related to the lack of space. This distribution of degrees of rotation can influence the analysis of predictability in mandibular incisors.

This study evaluated the effectiveness of mandibular incisor rotation correction by two different practitioners. Statistical analysis was performed to determine whether the results obtained were comparable or whether there was a significant difference between the two doctors.

The analysis shows that the accuracy of correction varies significantly according to the amplitude of the initial rotation. Small rotations (<5°) have an average correction rate of 68.2 ± 10.3%, while moderate rotations (5–15°) are corrected at 58.0 ± 13.2% and severe rotations (>15°) at 44.9 ± 10.5%. ANOVA highlights a highly significant difference between these three groups ($p < 0.001$), indicating that the greater the initial rotation, the lower the predictability.

When comparing the two practitioners, the results differ depending on the degree of rotation.

For small rotations (<5°), no statistically significant difference was observed between the two groups ($p = 0.411$). Correction rates were comparable (69.5 ± 11.1% for Operator A versus 67.4 ± 9.9% for Operator B, suggesting satisfactory similar outcomes for low-amplitude movements. However, for moderate rotations (5–15°), a statistically slight difference was observed ($p = 0.030$). Operator A achieved an average correction rate of 61.4 ± 15.4%, compared to 54.0 ± 8.9% for Operator B. This difference also becomes greater for severe rotations (>15°) ($p = 0.031$), with an average correction of 47.0 ± 11.7% for Operator A compared to 40.6 ± 5.5% for Operator B which can be explained with different orthodontics strategies.

These results suggest that both practitioners managed small rotations that same way, differences can be explained by the biomechanical complexity. The greater the amplitude of rotation, the more noticeable the inter-practitioner variability becomes. Furthermore these results show that the way in which rotation can be predicted depends not only on the intrinsic biomechanics of the aligners, but also strongly on the severity of the initial rotation. This implies that current methods of digital planning may not anticipate early correction needs in cases involving large rotations.

However, it is important to note that despite these slight statistical differences for moderate and severe rotations, correction rates remain below 65% overall in these groups, highlighting the inherent biomechanical limitations of rotational movements with aligners, regardless of the practitioner. Thus, the complexity of the movement seems to play a decisive role in the predictability of mandibular incisor rotations and could explain some of the differences

observed between operators. Other factors that can affect the results between both operators is the sequence of movements. Indeed Operator A shows slightly better results than operator B, and that can be explained by his sequence of movements for rotational correction. He used to divide the rotational movement into first, distal movement until the desired position and then a mesial movement until the full rotation correction.

Rotational movement is one of the most complex orthodontic movements to achieve with aligners. Unlike tipping or translational movements, rotation requires the creation of a pair of asymmetrical forces around the longitudinal axis of the tooth. However, the transmission of these forces depends heavily on the contact between the aligner and the coronal surface. The nature of the movement may contribute to the variability of results reported in the literature.

Mandibular incisors have a particular morphology: a narrow crown, a reduced coronal surface, and significant interproximal proximity. This configuration limits the contact surface with the aligner and reduces the ability to generate an effective rotational moment. In addition, the imperfect fit of the aligner at the proximal surfaces reduces the stability of the forces applied, which can lead to under-expression of the programmed rotations.

Thus, as the initial rotation amplitude increases, the biomechanical demands become more important. This may be explained by the gradual decrease in the percentage of correction observed in the 5–15° and >15° groups, as well as the appearance of differences between practitioners in these categories.

However, in addition to mechanical limitations, several uncontrollable components can also influence clinical results.

The first factor is patient compliance. Treatment with aligners requires wearing them for approximately 22 hours per day to ensure continuous and effective application of forces. In clinical practice, the actual wearing time cannot be objectively verified. A reduction in wearing time leads to a loss of continuity of forces and may compromise the full expression of planned rotations, thus increasing the need for refinements. Individual biological response is also a determining factor. The rate of bone remodeling, bone density, and periodontal ligament characteristics vary from patient to patient. This biological variability can directly affect the tooth following the sequence programmed by the software. Other uncontrollable factors

include attachment precision, material fatigue, root anatomy, movement sequencing, accessory use elastics and the quantity of surfaces in contact with the aligners … All of these parameters, combined with the intrinsic biomechanical limitations of rotational movement, may explain the variability observed between rotation groups and between practitioners, particularly for larger amplitude movements.

It therefore appears that the predictability of mandibular incisor rotations does not depend solely on digital planning, but results from a complex interaction between mechanical, biological, and behavioral factors, some of which are beyond the practitioner's direct control.

In order to give credibility to our results regarding the scientific papers, they were compared with other recent studies. Particularly, the study by Anto et al. (2024) reports particularly favorable results for lateral mandibular incisor rotational movements, with an accuracy of approximately 89.6% (18) . This means that the digitally planned movements were very close to the movements actually achieved clinically.

However, the results observed in our study are lower, particularly when considering the initial degree of rotation. For example, for rotations of less than 5°, an average correction rate of approximately 68% was observed. This difference could be explained by several factors. Indeed, the study by Anto et al. report does not clearly specify whether the results analyzed include one or more refinement phases. In fact, some studies with better results do not mention the use of the refinement process. Our results are from the first line of aligners without any refinement phases. However, the inclusion of refinements can improve the final result and artificially increase the reported accuracy, unlike most studies focusing on final treatment outcomes, this study evaluates rotational accuracy at the refinement stage, providing insight into the dynamic correction process and the limitations of initial treatment planning.

In this study, the authors also compared the accuracy of rotational movements in both mandibular and maxillary incisors. The findings indicate that mandibular incisors have a higher level of precision with approximately 88.3%, compared to 75.5% for maxillary incisors. The lower arch therefore appears to offer better predictability for rotational movements (18).

However, these results should be interpreted with caution, as the authors mention the possibility of overcorrection in some cases. Indeed, when the actual rotation slightly exceeds the planned rotation, this may artificially increase the reported accuracy percentage.

The article shows that the accuracy of rotational movements varies considerably depending on the type of tooth. In general, incisors show relatively high predictability, while canines and some premolars show less favorable results. Rotations of the canines are considered to be among the least predictable movements with aligners. In the study analyzed, maxillary canines showed the lowest accuracy of the entire arch, with an accuracy of approximately 63.3% (18).

This difference can be explained by biomechanical factors related to dental morphology. Incisors have a narrower crown and a relatively smooth surface, which facilitates aligner adaptation and force transmission. Conversely, canines have a larger crown and a longer root, making rotational movements more difficult to control with clear aligners.

In order to improve control of rotations for these more rounded teeth, certain clinical strategies have been developed, including the use of optimized rectangular attachments and IPR. These techniques increase the contact surface between the aligner and the tooth and improve the expression of rotational movements, particularly for so-called “round teeth” such as canines and certain premolars.

Similar results were reported by Bilello et al. (2022), who evaluated the accuracy of different orthodontic movements achieved with clear aligners. In their study, mandibular incisors showed high accuracy for rotational movements, reaching approximately 94.4% (24). In contrast, some posterior teeth, particularly the mandibular first premolars, showed significantly lower accuracy (70.4%). These results suggest that tooth morphology and biomechanical characteristics influence the predictability of orthodontic movements, with incisors generally being easier to move than canines and premolars.

These results are also consistent with those reported by Fiorillo et al. (2024), who studied the accuracy of rotational movements with transparent aligners. The authors report a median accuracy of about 70.7% for predicted rotational movements (25). This value is very close to that observed in our study for weak rotations (68.2%), which suggests that the rotations performed with aligners have moderate precision and these rotations remain dependent on several other parameters. In this same article by Fiorillo, they demonstrate that the most

complicated movements to complete are rotations as well as intrusion and extrusion, as well as the tooth type is a key factor to consider knowing the predictability of these corrections with aligners.

The results of this study show that the correction of mandibular incisor rotations with aligners has good predictability. These observations are consistent with data in the articles, which indicate that mandibular incisors are among the most predictable teeth in aligner treatment, unlike canines and premolars. These results confirm the influence of tooth morphology and biomechanical factors on the accuracy of orthodontic movements.

However, certain limitations of this retrospective study must be taken into account when interpreting the results. First, the sample size is limited to 40 patients, which may restrict the generalizability of the results. Second, the retrospective nature of the study does not allow for complete control of certain parameters that may influence clinical outcomes, such as patient compliance or actual aligner wear time. Nevertheless it reflects real world clinical conditions enhancing the external validity of our findings. Furthermore, the analysis focused exclusively on mandibular incisors, which limits the extrapolation of the results to other dental groups or other types of orthodontic movements. Future studies, including larger samples and prospective protocols, could provide a more accurate assessment of the predictability of rotational movements achieved with aligners.

6. CONCLUSION

The comparison between planned and achieved rotational movements revealed a significant discrepancy before the first refinement phase, confirming that ClinCheck® software predictions do not fully match clinical outcomes. These findings confirm hypothesis 1

Predictability of rotational correction decreased significantly as initial rotation amplitude increased, with correction rates of 68.2 ± 10.3% for small rotations (<5°), 58.0 ± 13.2% for moderate rotations (5–15°), and 44.9 ± 10.5% for large rotations (>15°) ($p < 0.001$). These findings confirm hypothesis 2. The study allows for a correction of rotational movements while the predictability nevertheless remains limited due to other factors such as biomechanics.

Moreover, by comparing the results obtained from the two operators. No statistically significant difference was observed between the two practitioners for small rotations ($p = 0.411$). However, small differences emerged for moderate ($p = 0.030$) and large rotations ($p =$

0.031), partially confirming hypothesis 3 and suggesting that clinical strategies influence outcomes for more complex movements.

These results must be interpreted considering additional factors influencing predictability, including crown anatomy, aligner wear time, attachment type, IPR, and aligner change frequency

7. SUSTAINIBILITY

This research is part of the Sustainable Development Goals (SDGs) defined by the United Nations, in particular, this work contributes directly to sustainable development goals, as this research aims to improve the reliability of orthodontic treatments and therefore the health and well-being of patients, which is SDG 3 (Good Health and Well-being). This paper promotes applied research and innovation in the biomedical field, which is consistent with SDG 9 (Industry, Innovation and Infrastructure). Finally, this thesis contributes indirectly to more sustainable and responsible orthodontic practice by avoiding the overproduction of clinical devices, which corresponds to SDG 12 (Responsible Consumption and Production).

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