Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

PREDICTABILITY OF THE INVISALIGN SYSTEM IN THE INCISORS MOVEMENTS

Madrid, academic year 2022/2023

Identification number: 170

SUMMARY AND KEYWORDS

Introduction: In recent years, the Invisalign® system has become increasingly popular thanks to its advantages in terms of aesthetics and comfort for the patient and its predictable results for the clinicians. That is why it is of great interest to analyze the predictability of the system in the anterior sector, as it is the most frequent reason for orthodontic treatment in our patients. **Objectives:** The objectives consisted in measuring the predictability of incisors' movements by comparing the initial prediction obtained with the ClinCheck® software with the final outcome. Crown and root movements were analyzed. A third objective was the influence of attachment types on the predictability of movements. Finally, the degree of root resorption present in incisors' after movement was analyzed. **Methodology:** An electronic search was performed in the following databases: PubMed, Scopus, Medline and Dentistry& Oral Science. Only articles dated of 10 years or less since the date of publication of this investigation were included, and only articles using the Invisalign® system were included. **Results:** After an extensive screening, 16 studies were selected. When examining crown movements; extrusion, intrusion, rotation and tipping were analyzed, whilst only torque and translation for root movements. For attachments' influence on movements, extrusion and torque were analyzed. Root resorption prevalence and external apical resorption were compared among the studies. **Conclusions:** Tipping seemed to be the most predictable of all crown movements. Translation movements seemed to be more predictable than torque movements. Invisalign® optimized attachments and Power ridges did not seem to have a significant effect on movements' predictability compared to other attachments used. Root resorption seemed to be quite prevalent but the amount of resorption was extremely low.

Keywords: Dentistry; Invisalign; Incisor; Predictability; Attachment.

RESUMEN Y PALABRAS CLAVES

Introducción: En los últimos años, el sistema Invisalign® se ha vuelto cada vez más popular gracias a sus ventajas respecto en cuanto estética y comodidad para el paciente y por sus resultados predecibles para el clínico. Es por ello que sea de gran interés analizar la predictibilidad del sistema en el sector anterior, al ser el motivo más frecuente de tratamiento de ortodoncia en nuestros pacientes. **Objetivos:** Los objetivos consistieron en medir la predictibilidad de los movimientos de los incisivos comparando la predicción inicial obtenida con el software ClinCheck® con el resultado final. Se analizaron los movimientos de corona y raíz. Un tercer objetivo fue la influencia de los ataches y Power Ridges® en la predictibilidad de los movimientos. Se analizó también el grado de reabsorción radicular presente en los incisivos después del tratamiento. **Metodología:** Se realizó una búsqueda electrónica en las siguientes bases de datos: PubMed, Scopus, Medline y Dentistry& Oral Science. **Resultados:** Después de una extensa selección, se seleccionaron 16 estudios. Al examinar los movimientos de la corona; se analizaron extrusión, intrusión, rotación y tipping, y solo torque y traslación para movimientos radiculares. Para la influencia de los aditamentos en los movimientos, se analizaron la extrusión y el torque. Se compararon la prevalencia de reabsorción radicular y la reabsorción apical externa entre los estudios. **Conclusiones**: El tip pareció ser el más predecible de todos los movimientos. En cuanto a los movimientos de traslación fueron más predecibles que los movimientos de torque. Los ataches optimizados de Invisalign® y los Power Ridge® no parecieron tener un efecto significativo en la predictibilidad de los movimientos en comparación con los otros ataches utilizados. La reabsorción de la raíz parece ser bastante frecuente, pero la cantidad de esta es extremadamente baja.

Palabras llave: Odontología; Invisalign®; Incisivo; Predictibilidad; Atache.

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INTRODUCTION

During the past decades, there has been an increasing aesthetic demand in dentistry, especially in the orthodontic field. White and aligned teeth are the goal of many, especially the new generation, that feels more confident and attractive with aligned teeth. (1) The high aesthetic demands are not only related with the end of the treatment, but also with its duration. Patients do not want to be seen with fixed appliances on, especially adults (2), and prefer wearing invisible appliances, especially in the aesthetic zone. (1)

This is the reason why, more than 50 years ago, dentists started trying to engineer an invisible appliance that would move teeth like fixed appliances did. Already in 1945, Kesling fabricated an invisible appliance to refine the finishing movements of a fixed appliance treatment. (3) In the following years, dentists continued developing this idea by using the vacuum machine to produce aligners, but it was only in 1997 where a big progress was made. Two Stanford University students, Kesley Wirth and Zia Chisti, were able to merge their three-dimensional computer knowledge with mass production capabilities, and founded the Align company. (3) This system was able to replicate a three-dimensional simulation of the movements accomplished by the teeth during the orthodontic treatment and, at the same time, mass produce custom-made invisible aligners. Since the founding of Align technology, the Invisalign® company has remained leader in the clear aligner market and has continuously been improving its technology, allowing clinicians to treat complicated cases. (4)

As clinicians have been increasingly using this system in the last two decades, there is an increasing need to investigate the predictability of this system, in terms of crown and root movements, especially in the incisors' area, a highly aesthetic zone.

The purpose of this introduction is to describe the state of the art of the Invisalign® methodology; from the diagnostic records, through the planning and production process, and the advantages and disadvantages perceived by the clinician and the patient.

1.1. Indications of the Invisalign® system

As stated by Kumar et al. (5), the principal indications for Invisalign® treatment is the resolution of mild crowding (1-5 mm), deep overbite treatment and molar distal tipping. In addition, as highlighted by Dai et al.(6), Invisalign® does seem to be indicated for quite complex treatments, such as extraction cases or skeletal discrepancy cases.

However, it can be quite challenging, this is mainly due to two reasons: firstly, as it will later be highlighted more thoroughly, the biomechanics of clear aligners work mainly by crown tipping and acting indirectly on root torque, secondly, treatment times with clear aligners stage movements because of the SmartStage® technology, so that the overall treatment predictability is improved, but this might take a bit longer. (7) However, it must be stated that increased treatment duration does not seem to be a problem for most patients compared to fixed appliances (1,2), as their invisible characteristic is not as unaesthetic as fixed appliances.

Figure 1. iTero intraoral scanner for Invisalign® (10)

Other than the case selection, a key element for treatment success is patient cooperation. (3,5) Contrary to fixed appliances, removable appliances need minimum 22 hours of wear to accomplish proper tooth movement. (8) As highlighted in the biomechanical section, clear aligner forces are very light and tend to disappear with time; therefore, patient cooperation needs to be checked continuously.

1.2. Diagnostic Records Process

The clinician, after having evaluated the patient characteristics (mild to moderate case difficulty and good motivation to cooperate), will proceed to obtain an accurate impression of the teeth position. This is usually obtained in two ways: either with a polyvinylsiloxane (PVS) impression or with a digital scanner, as shown in Figure 1. (3,9)

Together with impressions, an interocclusal record, either wax (analogic) or digital, must be taken to locate the arch impressions spatially. Additionally, intraoral and extraoral photographs, together with a panoramic or cephalometric X-ray is sent digitally or analogically to the Invisalign® center based in Santa Clara. (9,10)

1.3. Cephalometric Analysis and Incisor position

As stated beforehand, it is highly recommended that, during the diagnostic record process, the clinician obtains a cephalometric X-ray. This type of X-ray, a sagittal X-ray of the cranium and the oral structure, was introduced in the middle of the 20th century and allows the clinician to analyse the cranial and dental structures in numerous ways; one of the first and most used analysis is the Steiner analysis. (11)

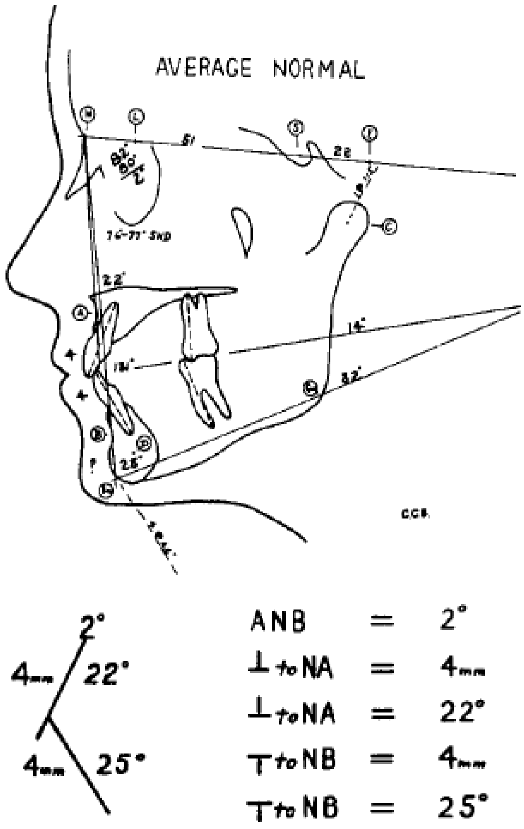

Figure 2. Steiner analysis in cephalometry (11)

Steiner analysis takes as a reference plane the line joining the sella turcica (S) to the nasion point (N) and relates the incisors' position to it. By obtaining these values from a large sample of patients, Steiner was able to obtain a number of ideal values for the correct positions of incisors. However, these differ depending from the population type, as different races have different cranial structures. (12)

The ideal values suggested by Steiner are both 4 mm distance from the incisor tip to the A point for the upper incisor and to the B point for the lower incisor, and a 22 and 25 degrees angle formed by the teeth axis and the A and B points, respectively for the upper and lower incisor. The interincisal angle should be of 131 degrees, as depicted in Figure 2.

In addition to these ideal values, in its planning, the clinician should strive to obtain ideal overbite and overjet values, respectively 1/3 of the lower incisor covered and 2 mm of distance between the lower and the upper incisor. (11)

1.4. The Clincheck® process: A crucial step

In the Invisalign® headquarters, the analogic records are digitized through impression scanners that use Computed Tomography technology to be as accurate and as efficient as possible. All this information is placed into a 3D software that merges all these records and sends them to the Invisalign® center in Costa Rica where the treatment stages are planned. (9)

There, with the help of computer technology and specialized operator ability, Invisalign® is able to produce a treatment plan named as ClinCheck®, highlighting all the stages of aligners' change.

This treatment plan is sent digitally to the clinician, that has the possibility to control all the phases of the treatment, visualize the final outcome of the treatment and modify what is incorrect in his/her opinion. In this phase, the clinician's ability in adapting the ClinCheck® to the individual case is quite important and oftentimes decisive in moderate/hard to treat cases (4), as certain teeth movements seem to be less predictable than others (13,14) , so that the clinician should be able to avoid or control these unpredictable movements.

A basic knowledge of clear aligner biomechanics and materials, especially of the Invisalign® system, is necessary for a good treatment planning.

1.5. Invisalign® Material: SmartTrack®

Clear aligners can be constituted by a large number of materials such as modified polyethylene glycol (PET-G), polycarbonate, polyproprene or polyurethane. (15) The quality of these materials and their thickness (varying from 0.5 to 1.5 mm), greatly influences the force that is applied to the tooth, and most importantly its rate of disappearance. (12)

After many years of research and development, Invisalign® has developed a unique material for its aligners, named SmartTrack®, that seems to have a number of advantages compared to standard clear aligner materials. (7)

In addition to being inert, biologically stable and hypoallergic, the material seems to be able to deliver an optimal load during the two-week period of wear of the aligner. (7)

This is a crucial aspect of treatment success, as the main problem present in aligner

treatment was the relatively large force decrease that occurs in the initial days of clear aligner wear, resulting in a high force at the start and a very low at the end of the two-weeks period.
With the SmatTrack® material instead, a smaller initial load was present at aligner insertion, that was relatively constant during the two week period, the usual period of aligner change, that can vary depending on the practitioner’s present, varying from 7, 10 and 14 days. (16) However, even if at the time of insertion the SmartTrack® material has a smaller load, after some days it decreases to a lower level than initially but delivers a higher load than the material in most aligners. (17) This leads to a very gentle and light force, the optimal amount of force to have tooth movement without root resorption or ischemia, about 25g of force. (8)
Another very important quality in terms of patient’s comfort and experience, is the higher elastic property of the SmartTrack® material, that adapts better over the teeth surfaces and is less likely to break compared to harder clear aligner materials. (7) This should lead to more precise tooth movement due to aligner adaptation and shorter treatment time, as aligner breakage can increase treatment time. This flexibility adapts better to the surface of the teeth, the interproximal spaces and the attachments, so that tooth movement is more controlled. (17)
This improved fit is claimed by the company through the “Blue Gel Test”, performed by applying a colored gel under the SmartTrack® material and confronting the relative lower opacity compared to the gel applied under a standard clear aligner material. (7)
Lastly but not least importantly, this material seems to be less susceptible to stains, has good clarity and is almost invisible compared to other aligner materials that seem to be more perceivable to the human eye. (18) This is a crucial characteristic that improves patient’s cooperation and patient’s satisfaction at the end of the treatment. (1,2,19)

1.6. Invisalign® Force: SmartForce®

As highlighted by Lanteri et al. (20), movements performed by one aligner are in the order of 0,15 to 0,25 mm, meaning that 1 mm of movement is usually achieved by 5 aligners in about 10 weeks, if they are worn at least 20-22 hours per day. (21)

However, most movements, except crown tipping, need special attachments to be performed correctly. This is because aligners base their force on the crown away from the center of resistance; therefore, attachments provide a way to create couples and forces closer to the center of resistance of the teeth.

Invisalign® developed throughout the years a wide array of specially designed attachments for every type of tooth movement, from power ridges (18) to beveled attachments. (7) These attachments seem to have more retention compared to the traditional ellipsoid attachments and generate more effective force couples to execute complicated movements such as canine rotation. (22) Attachments are also very important for anchorage, as, even in intrusion movements, that are performed by aligners without attachments, these have to be placed in anchorage teeth to prevent extrusion. Therefore, careful attachments' design planning in the ClinCheck® phase is very important for treatment success. (13) In this review, it will therefore be very important to investigate the influence that Invisalign® attachments have on the predictability of teeth movements.

1.7. Invisalign® Planning: SmartStage®

In complicated and long treatments, such as extraction cases, a detailed and careful planning is needed. The SmartStage® technology seeks to ameliorate the treatment outcomes by diminishing the number of interferences or premature contacts that can happen during treatment through three-dimensional simulation and by staging complex movements. (17) For example, when canines and incisors need to be retracted in a first premolar extraction case; in a first stage only the canine is retracted and, in a second moment, the incisor group is retracted en-masse so that an improved posterior anchorage is achieved. (7) Even if this staging increases treatment time, it greatly improves treatment outcome predictability, as, oftentimes, when incisors are retracted with aligners, if the posterior anchorage is not optimal, a steepening of the Curve of Spee occurs, due to uncontrolled root movements. (17) In addition, Chang et al. (7) advocate that movement staging in aligners is a very good option as the diastemata that would be seen in fixed appliance treatments are filled by the aligners and are therefore not seen.

A unique feature of the SmartStage® technology is that it is a "force-driven system", meaning that the forces applied to the crowns and roots by the aligner are programmed in accordance to the biomechanical principles of orthodontic movements. (17) This is the opposite to the previous idea of an aligner based on a "displacement-driven system" where the force applied is based on tooth movement, so that this might be excessive and result in root resorption or uncontrolled movement. (23) This software allowing a more precise staging of tooth movement is one of the numerous innovations introduced by Invisalign® throughout the years of its evolution.

1.8. Invisalign® Generations: a continuous evolution

Since its conception in 1999, Invisalign® has continuously updated its system, at times drastically changing its mode of action. The first aligners produced by Invisalign®, the G1, were mainly based on the "displacement-driven" concept, with the aligner shape delivering the force to the tooth without any use of attachments, that, at the time, were not used at all. (24) After less than a decade, in 2009, Invisalign® upgraded its system to G2, introducing attachments that were adapted to the patient case and Power ridge attachments. (8) After just one year, the G3 was introduced; optimized attachments for rotation of premolars and Power ridges for the lingual movement of upper incisors were implemented. In addition, at this moment, Invisalign® began to approach the idea of treating Class II and Class III cases by introducing Precision Cuts, pre-cuts present in the aligners where the patient could place interarch elastics for the correction of sagittal malocclusions. (24) After tackling the sagittal problems, Invisalign® started to tackle vertical malocclusion in 2011, with the G4 system, by introducing special extrusion attachments to correct open bites. (25) A year later, in 2012, Invisalign® introduced its SmartTrack® material that, as described above, delivers optimal load and has a good elasticity to adapt to the tooth surfaces. (7) After addressing open bites with extrusion attachments, in G5, Invisalign® developed specific attachments to achieve incisor intrusion and premolar extrusion for deep bite cases, whilst, at the same time, precision bite ramps were introduced to disocclude posterior teeth while opening the bite. (24)
After vertical cases, in 2014, Invisalign® introduced a great innovation: the treatment of extraction cases with aligners by using special retraction attachments for canine

movement and, after canine retraction, by staging movements through the SmartStage® technology and optimized anchorage attachments for posterior anchorage, incisor en-masse retraction. (17) In 2016, with the G7 system, after addressing complex cases in the previous generations, Invisalign® concentrated in the finishing aspects of the treatment, improving attachments for molar retention and upper lateral movement. (24) Finally, in 2020, with the G8, the latest generation up to now, Invisalign® started to handle transverse problems such as crossbites by introducing special rotation and extrusion attachments for molars, so that the possibility of buccal crown tipping is reduced. (7,26) Additionally, with the G8 system, Invisalign® improved the treatment of deep bite cases by implementing special lower incisor intrusion attachments to improve anchorage and avoid aligner lift-off. (26) Finally, in the last years, as shown in Figure 3, due to the increasing aesthetic demand, dentists are able to align and brighten teeth simultaneously with Invisalign®. (24)

In addition to generation system development throughout the years, Invisalign® specifically implemented attachments for specific movement types on specific teeth, as examined in the following pages.

Year	Updates
1999	Sales began
2000	first case report by Boyd
2008	Align instiute
2009	**Smart Force attachments**
2010	**G3** Precision Cuts for Class II/III inter maxillary elastics
2011	**G4** Optimized Extrusion Attachments for anterior teeth during treatment of open bites
2012	**Smart Track aligner material**
2013	**G5** deep bite correction, precision bite ramps
2014	**G6** Premolar extraction cases Optimized Retraction Attachments for bodily movement during canine retraction Optimized Anchorage Attachments
2016	**G7** Molar retention attachments prevention of posterior open bites
2020	**G8**- Crowding crossbite, pGosterior expansion and deep bite cases
2020	Clincheck™ PRO 6.0 and clincheck "in-face" visualization for invisalign treatment
2021	Professional whitening system optimized for invisalign aligners and vivera retainers

Figure 3. Invisalign Generations throughout the years. (24)

1.9. Invisalign® attachments for tooth movements

An in vitro study examining aligner design came to the conclusion that it was impossible to perform a correct translational movement without any particular modification such as a more rigid area cervically or a pressure point near the crown. (27) This highlights how important aligner design and attachments presence are in achieving a correct movement predictability. In addition to aligner design, aligner force is crucial, especially in lingual movements, as, as aligner fit increases, the force generated by the aligner increases. (8) An in-house aligner would very difficultly be able to control this subtle force delivery difference between aligners for each tooth. For lingual movements, it is advised to never exceed 0.5mm for the maxillary incisors, otherwise root resorption and uncontrolled movement could occur. (27)

When performing extrusion movements with the aligners, a "wobbling", non-linear crown and root movement seems to occur, resulting in a very inaccurate movement. (8) However, in the study by Kravitz et al (13), a mean predictability of 55% for extrusion movements was found, possibly because optimized attachments were used. These attachments are beveled on the gingival side and are systematically placed by the software in the ClinCheck® planning when an extrusion of more than 0.5mm is programmed, demonstrating the crucial role that these attachments play in improving open bite cases. (8) However, if more than 2 mm of extrusion need to be performed, the software prescribes the use of intermaxillary elastics to correct this problem. (7)

Instead, when performing intrusion movements, attachments are not normally needed, except in anchorage teeth, to avoid aligner liftoff. (26) These attachments will be rectangular to provide anchorage and a small extrusion of premolar to correct the curve of Spee in deep bite cases, where incisor intrusion is needed. (8) During intrusion, it is particularly important to control the vestibule-lingual tipping that can occur, as incisors could enter in contact with the lingual or cortical bundle, resulting in root resorption. (23) In order to perform torque movements, Invisalign® implemented Power Ridges that, as outlined in Figure 4, in order to create lingual torque, deliver pressure in the cervical lingual area of the tooth, which, after encountering aligner resistance in the buccal side, performs a lingual torque movement as a result of a force couple generation. (14)

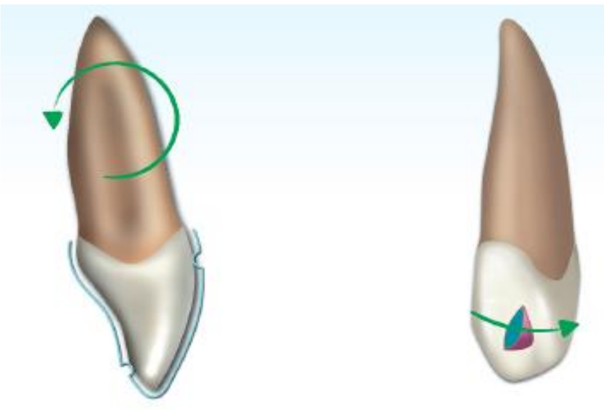

Figure 4. Power ridges® on the left and attachments on the right. (7)

Use of couple forces was also originally used for rotation movements by attaching buttons on the buccal and lingual sides of teeth and by changing elastic chains continuously. (8)

However, optimized rotation attachments are much more practical and seem to be more predictable than couple force generation in performing rotation movements. (28) During all these movements and the treatment duration, the practitioner will have to continuously check for indications on whether the teeth are moving as planned, as indicated in the following paragraphs.

1.10. Aspects checked by the practitioner during treatment

Even if Invisalign® designs the best technology, it still relies on a correct implementation by the practitioner, that will have to check numerous aspects during the treatment and adapt accordingly in order to reach a successful clinical outcome. A common problem encountered during aligner change is the presence of a gap between the aligner and the teeth, this is oftentimes cause by a non-performed incisor extrusion or by a canine distal movement lifting off the opposite side. (7) The clinician will have to consider whether to maintain the same aligner instead of changing it, because the patient might have tried to accelerate the treatment by changing the aligner prematurely, or to advise the patient to bite on “chewies”, plastic devices, that force the aligner back into place by using the force of mastication. (24) Another aspect that the practitioner should always check during treatment is the presence of the intact attachments on teeth surfaces as these tend to detach with time. (7) Patients should even be advised to check every night with their finger the presence of the attachments and, if they detect a change, they should immediately call for an appointment with their practitioner. An ultimate crucial aspect that influences overall treatment success seems to be anchorage checking as uncontrolled movement can happen, even if correct movements are performed, therefore, the practitioner might have to consider to improve the ClinCheck® planning by adding anchorage add-ons such as temporary anchorage devices (TADs) or other devices. (8) At the end of treatment the practitioner is able to always check the degree of achieved movement compared to the planned movement in the ClinCheck® by digitally superimposing the final scan of the treatment with the initial scan. (29) However, in order to precisely superimpose the digital scans, many different methods are used and technical ability by the practitioner is required. (30,31) One of the simplest and quite accurate way to perform this analysis is by taking the occlusal plane as a reference point and compare the tooth movements relative to the plane. (29) Another, more time consuming method is to segment the arch and analyse each teeth separately by taking reference points in the teeth, these reference points are different and vary from tooth to tooth and practitioner to practitioner. (30–33) Finally, a simpler method that has become more and more popular throughout the last decade, is the best fit surface method: this consists in using special softwares that automatically superimpose the surfaces of two or more impressions and find a best fit result, where differences between the achieved and the predicted movement can be calculated relatively easily. (34–36) Obviously, this is a method that is prone to the potential error of the software but is objective and is not based on users' ability and experience in using the software, thus more easily comparable among studies using the same best fit surface software.

1.11. Advantages of the Invisalign® system

The main advantage of the Invisalign® system is that aligners are clear and invisible. This is particularly important for adults and teenagers, less for children, that do not seem to be as concerned as teenagers about their appearance. (1) An important advantage that the Invisalign® system offers, as depicted in Figure 5, is that through the Clincheck® the user is able to see the crown position and predict how the root will be exactly positioned by merging the CBCT with the intraoral scan, therefore root movements can be planned and measured during treatment; this cannot be normally done in traditional aligner planning. (37)

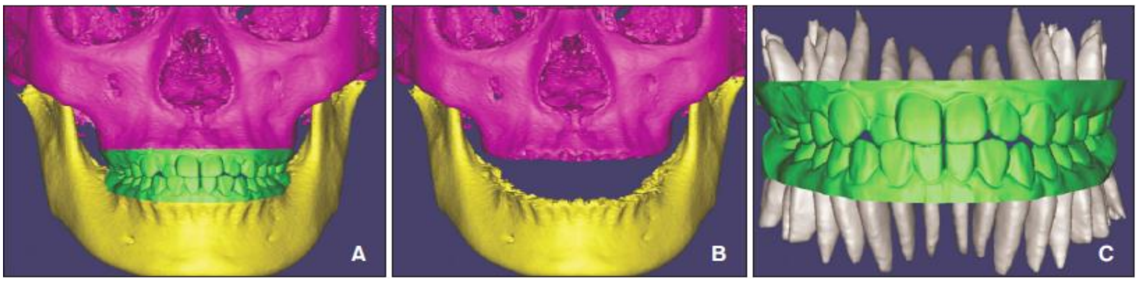

Figure 5. Integration of CBCT of the two maxillary arches (B), with the intraoral scan (A), so that root positions are calculated with crown position (C). (37)

Another quite important aspect of the Invisalign® treatment compared to fixed appliance is its removable quality, allowing the patient to remove the aligner when eating, so that there is not only more patient comfort, but also a better periodontal health, as the patient is able to floss and brush more easily. (20,21) Similarly, aligners do not cause any gum lesions and can be used in patients allergic to nickel, contrary to fixed appliances. (3)

In addition, after COVID-19 and in prevision of a future pandemic, digitally planned aligners could represent a better option than fixed appliances, as there will be reduced treatment time, less contact with patient saliva and instructions and check-ups can be done digitally, reducing contact with patients and transmission. (24)

Speech is also less affected compared to traditional removable appliances, as the palate is not covered. (19) Finally, but more specifically to the Invisalign® system, during the Clincheck®, the clinician can individually plan and slow down certain critical movements that could otherwise cause pain in certain pain-sensitive patients. (9)

1.12. Disadvantages of the Invisalign® system

The main disadvantage of this methodology is that it completely relies on patient compliance. As outlined beforehand, the patient needs to wear the aligner for minimum 20-22 hours per day continuously for the whole duration of treatment that is usually longer than fixed appliance treatment and that does not rely on patient's compliance. (38) In addition, even if it happens in very rare occasions, some patients can also be allergic to the Invisalign® material, so that the clinician might be confronted with symptoms such as swollen oral mucosa, swollen lips or airway obstruction; in this cases the treatment should be suspended. (17) Also, at the end of orthodontic treatment, it will be absolutely necessary for the patient to wear a fixed retention to prevent retreatment. (20) Finally, as outlined by a large number of reviews, certain tooth movements seem to be less predictable than others, such as rotation, torque and translation, averaging 40% of predictability in certain studies (13,22), certainly not enough for clinicians to be sure about the success of their treatments. Knowing the predictability of the Invisalign® system based on the movement types is of crucial importance for the aesthetic zone, as more and more importance is given to this aspect of the therapy. (2) In addition, it is quite important to investigate the difference in predictability between crown and root movements, as root movements seem to be less predictable than crown movements. (39) On a similar note, root resorption induced by Invisalign® is also quite important to investigate, as, even if root movements could be predictable, a resorption induced by an Invisalign® treatment will be an iatrogenic damage.

In addition, as stated beforehand, the influence of Invisalign® attachments compared to traditional attachments will be investigated, as these greatly influence tooth movement. (40)

The hypothesis, as stated beforehand, is that movements involving the crown, such as tipping, are much more predictable than movements involving the root, such as translation and mass movement. Similarly, regarding attachments, Invisalign® attachments should lead to more predictable movements.

OBJECTIVES

Primary objective:

1) To determine the predictability of incisors' crown movements performed with the Invisalign® system compared with the ClinCheck® prediction.

Secondary objectives:

2) To determine the predictability of incisors' root movements performed with the Invisalign® system compared with the ClinCheck® prediction.
3) To compare the influence of attachments on the predictability of incisors movements performed with the Invisalign® system compared with the ClinCheck® prediction.
4) To determine the amount of root resorption present in incisors after the Invisalign® system compared with the initial root length.

MATERIAL AND METHODS

An electronic search was performed in the following databases: PubMed, Scopus, Medline and Dentistry& Oral Science.

Based on the objectives previously outlined, the search was performed using the following combination of keywords, resulting in these search equations:

1) (incisor*) AND (invisalign*) AND ((predictability) OR (reliability) OR (accuracy) OR (effectiveness) OR (validity))
2) (incisor*) AND (invisalign*) AND (root resorption)

The inclusion and exclusion criteria are outlined in the following table (Table 1):

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Dated of 10 years or less	Dated of more than 10 years
Invisalign® treatment	Other aligners used
Languages: English	
	Extractions or mini-implants in treatment
Full text available	No full text available
	Studies in-vitro or on animals

RESULTS

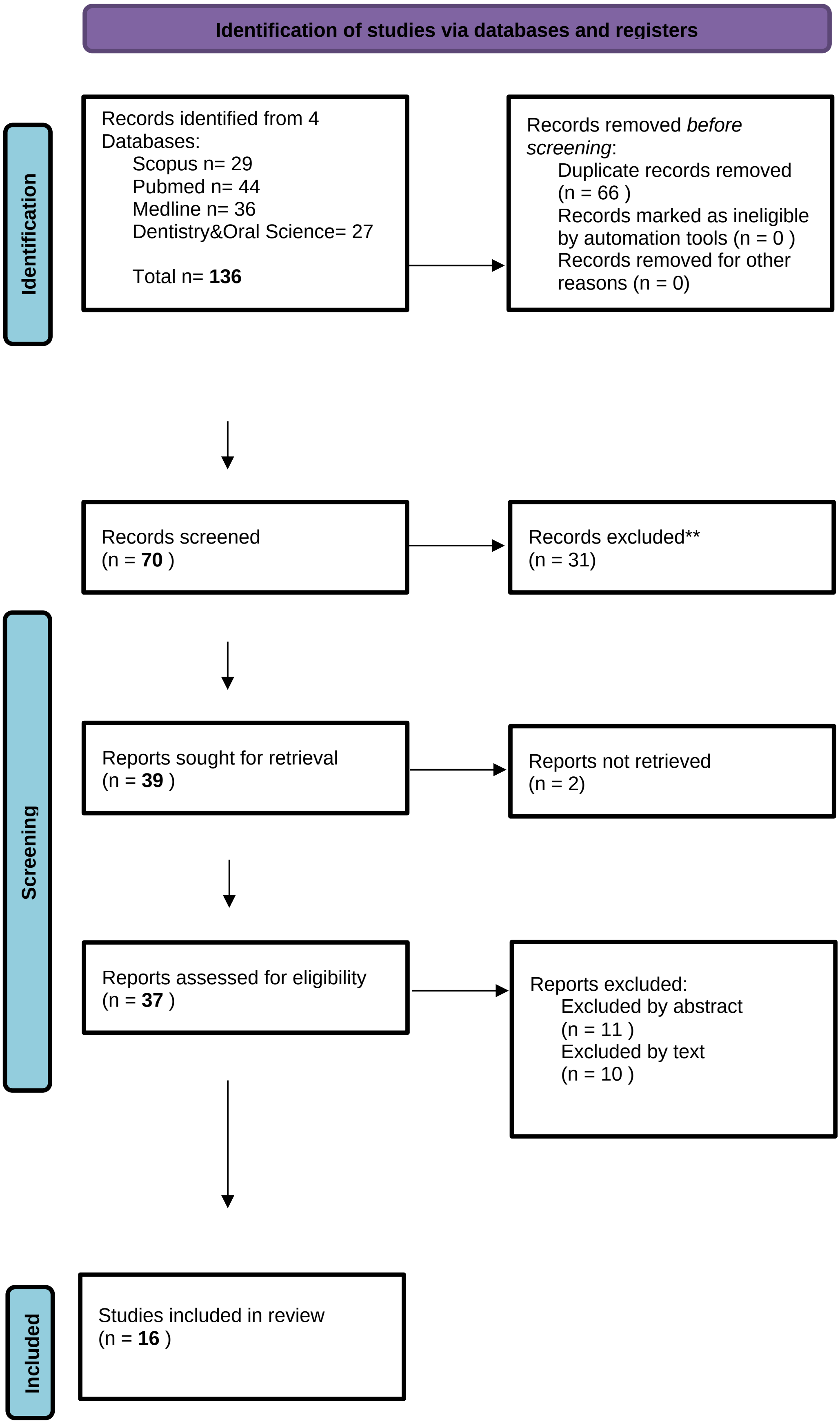
Identification of studies via databases and registers
Identification
Records identified from 4 Databases:
Scopus n= 29
Pubmed n= 44
Medline n= 36
Dentistry&Oral Science= 27
Total n= 136
Records removed before screening:
Duplicate records removed (n = 66)
Records marked as ineligible by automation tools (n = 0)
Records removed for other reasons (n = 0)
Screening
Records screened (n = 70)
Records excluded** (n = 31)
Reports sought for retrieval (n = 39)
Reports not retrieved (n = 2)
Reports assessed for eligibility (n = 37)
Reports excluded:
Excluded by abstract (n = 11)
Excluded by text (n = 10)
Included
Studies included in review (n = 16)

Figure 6. PRISMA flow diagram.(41)

Table 2. Predictability of incisors' crown movements.

Study	Study sample	Location	Tooth type	Extrusion	Intr.	Tip	Rotation
2022, Bilello et al (29)	10	Maxilla	Central		91.1	80.7	96.1
			Lateral		91.8	95.9	80.9
		Mandible	Central		98	97.5	94.4
			Lateral		92	91.6	90.5
2020, Haouili et al (35)	38	Maxilla	Central	56.4	33.4	55.8	58
			Lateral	53.7	44.6	62,2	51.7
		Mandible	Central	44.5	33.9	58.4	47.2
			Lateral	47.1	36.7	59.4	47.2
2021, Jiang et al (39)	69	Maxilla	Central			65.0	
			Lateral			65.8	
		Mandible	Central			72.3	
			Lateral			71.6	
2021, Karras et al (30)	100	Maxilla	Central	66.3			
			Lateral	46.3			
		Mandible	Central	48.5			
			Lateral	48.5			
2022, Smith et al (32)	42	Maxilla	Central				
			Lateral				
		Mandible	Central			35	
			Lateral			35	
2017, Grünheid et al (36)	30	Maxilla	Central	*	*	*	
			Lateral				
		Mandible	Central	*	*		
			Lateral	*	*		

2018, Charalampakis et al (33)	20	Maxilla	Central	128.1	37.4	78.9	57.2
			Lateral	127.8	31.4	77.1	66.2
		Mandible	Central	86.6	25.6	98.2	75.6
			Lateral	86.6	25.6	98.2	75.6
2020, Al-balaa et al (31)	22	Maxilla	Central		48.3		
			Lateral		55.8		
		Mandible	Central		44.3		
			Lateral		44.3		
2014, Maree et al (14)	30	Maxilla	Central			69.2	71.3
			Lateral				
		Mandible	Central				
			Lateral				

Explanation. *statistically significant difference.

In the study by Haouili, values are obtained by an average calculation between vestibular and lingual for tip, and between mesial and distal for rotation.

Table 3. Predictability of incisors' root movements: torque and translation					
Study	Study sample	Location	Tooth type	Torque	Translation
2021, Jiang et al (39)	69	Maxilla	Central	31.83	43.21
			Lateral	31.70	39.86
		Mandible	Central	40.62	57.95
			Lateral	37.20	54.73
2017, Grünheid et al (36)	30	Maxilla	Central	*	
			Lateral		
		Mandible	Central		
			Lateral		
2014, Simon et al (42)	26	Maxilla	Central	50.3	
			Lateral		
		Mandible	Central		
			Lateral		
2021, Gaddam et al (43)	40	Maxilla	Central (v/l)	21.2/ 116.3	
			Lateral (v/l)	15.5/ 92.7	
		Mandible	Central (v/l)	64.7/ 114.2	
			Lateral (v/l)	64.7/ 114.2	

Explanation. *statistically significant difference. In Simon et al, values are obtained as an average for the same tooth type (for example 21 and 11). In Gaddam et al, torque values are for vestibular and lingual movements.

Table 4. Comparison of the different effects of attachments on the predictability of incisors movements.

Study	Study sample	Location	Tooth type	Extrusion (o/c)	Torque (att/PR)
2021, Karras et al (30)	100	Maxilla	Central	58.7/ 73.9	
			Lateral	44.8/ 48.3	
		Mandible	Central	64.8/ 27.7	
			Lateral	64.8/ 27.7	
2014, Simon et al (42)	26	Maxilla	Central		49.1/51.5
			Lateral		
		Mandible	Central		
			Lateral		
2022, Smith et al (32)	42	Maxilla	Central		
			Lateral		
		Mandible	Central		0.5 mm greater apex movement
			Lateral		

Explanation. In the study by Karras et al, optimized and conventional attachment values are presented. Simon et al instead, present conventional attachment values and power ridge values.

Table 5. Root resorption in incisors: root resorption prevalence (%) and external apical resorption (EARR in % and in mm).

Study	Study sample	Location	Tooth type	Resorption	EARR
2020,	70	Maxilla	Central	69.4	
Li et al (44)	35		Lateral	69.4	
	Invisalign®	Mandible	Central	60	
			Lateral	53.9	
2017,	372	All	All teeth	52.8	
Iglesias et	159				
al (45)	Invisalign®				
2017,		Maxilla	Central	46	
Gay et al	71		Lateral	40	
(23)		Mandible	Central	38	
			Lateral	44	
2021,	40	Maxilla	Central	All teeth had	7.31
Liu et al			Lateral	resorption	8.0
(46)		Mandible	Central		8.8
			Lateral		7.7
2021,	56	Maxilla	Central		0.47
Gandhi et al	3 studies		Lateral		0.41
(47)	reviewed	Mandible	Central		
			Lateral		

Explanation. In the studies by Liu and Gandhi, the vales for external apical resorption are obtained as an average for the same tooth type (for example 21 and 11).

DISCUSSION

5.1. Predictability of crown movements

Regarding the first objective investigated in this work, namely the predictability of incisors' crown movements, the articles examined used different methodologies. Most of the studies (29,30,32–36) used three digital records obtained with a digital scanner and superimposed them by using different methods. However, only two studies, namely the ones by Jiang et al. (39) and Al-balaa et al. (31), superimposed the digital records taken with intraoral scanners with CBCT records taken at the start and at the end of the treatment.

Another quite important difference among the studies examined was the great differences in the methods used to superimpose the records between them. In the study by Bilello et al. (29) for example, the occlusal plane was used as a reference point to compare the tooth movement. In other studies (30,32,33), a segmentation method was used; every tooth was "sliced" in the digital model and its movement examined separately. For specific movements, specific reference points were chosen differently depending on the study; for example, in the study by Karras et al. (30) a point at the center of the incisal edge or cusp tip was taken, whilst in the study by Al-balaa et al. (31) the long axis of the incisor was taken as a reference point.

Another method used in other studies (34–36), was a best fit method; the program recognizes special reference points and estimates the movement performed.

Obviously these great differences in the methodologies and the small number of studies integrating CBCT records in their methodology greatly influence the validity of the results obtained.

5.1.1. Extrusion

The movement of extrusion seems to have a predictability of around 50% in 2 studies(30,35) and shows a statistically significant difference between the predicted and the actual movement in the study by Grünheid et al. (36). However, in the study by Charalampakis et al. (33) an over performance of the extrusion movement is present in maxillary incisors, with values around 128%, while in mandibular incisors an underperformance of extrusion is observed, with a value of 86.6%; a higher predictability than in the previous studies.

5.1.2. Intrusion

When examining intrusion movements, very high values, reaching 90% predictability, are observed in the recent study by Bilello et al. (29). However, significant lower values, averaging 30% can be observed in the other 4 studies (31,33,35,36) analyzing this movement, that seems to have a lower average predictability than its opposite, namely extrusion.

5.1.3. Tipping

Tipping movements, also seem to be more predictable than the previous ones, as in 3 studies they have values between 69.2% and 98.2% (29,33,34) and in the study by Grünheid et al (36) no statistically significant difference is observed in 3 out of the 4 tooth types examined. However, in the other 3 studies (32,35,39), values for tipping ranged from 35% to 72.3%.

5.1.4. Rotation

The last crown movement examined was rotation, that, in 2 studies (29,34), had quite high values ranging from 71.3% to 96.1%, while in other 2 studies (33,35), the values were lower, ranging from 47.2% to 75.6%.

5.2. Predictability of root movements

Regarding the second objective investigated in this work, namely the predictability of incisors' root movements, both root movements, torque and translation, have significantly lower values than crown movements.

5.2.1. Torque

Concerning torque movements, values ranging between 31.70% to 40.62% in the study by Jiang et al (39) are similar to the value obtained for maxillary central torque in the study by Simon et al (42).

On the contrary, in the study by Gaddam et al. (43), underperformance of vestibular torque is observed in all incisors, especially in maxillary incisors, with values of 21.2% and 15.5%. In lingual torque movements, an over performance of the movement is observed in observed in all tooth types except in maxillary lateral incisors.

In addition, in the study by Grünheid et al. (36), no statistically significant difference in torque movements is observed in all tooth types except in maxillary central incisors.

5.2.2. Translation

When examining translation movements, the only study examining this type of movement was the one from Jiang et al. (39), showing higher values than in torque movements, an increase of about 10% in values is observed.

5.3. Influence of attachments on movements

Regarding the third objective investigated in this work, namely the effects of attachments on incisors' movements, the results are very diverse and seem to have been influenced by a number of variables. In the study by Simon et al. (42), the influence of staging of the aligners (changing the aligners slowly and faster) was analysed at the same time of the effects that different attachments had on movement, thus partially influencing the outcomes.

In the study by Karras et al. (30), when examining extrusion movements, optimized attachments have lower values than conventional attachments in maxillary incisors, whilst in mandibular incisors optimized attachments (64.8%) had significantly higher values than conventional attachments (27.7%). When examining the effect of attachments on torque movements, the study by Simon et al. (42) shows very similar values between conventional attachment and the newer Power Ridge features of

Invisalign®. Finally, in the study by Smith et al. (32), attachment presence increased apex movement by 0.5 mm in torque movements.

5.4. Root resorption with Invisalign®

Regarding the fourth objective investigated in this work, namely root resorption present in incisors' movements, different investigation methods were used.
Most studies (44,46,47) used CBCT images to measure root length at the start and end of the treatment. Only in the study of Iglesias-Linares et al. (45), calibrated panoramic radiographs were used to measure external apical resorption. Regarding data analysis, in the study by Li et al. (44) two blinded investigators examined the data and used Chi-squared and paired t tests to analyse and place in comparison the root lengths. Similarly, Liu et al. (46) used paired t-tests and multiple linear regression to accomplish the same objective of comparing the root lengths and eliminating the bias.
In the study by Liu et al. (46), all teeth seemed to have some resorption at the end of the Invisalign® treatment, whilst in the rest of the studies a smaller amount of resorption seemed to be present: the study by Li et al. (44) had the highest value with 69.4%, whilst Iglesias et al. (45) and Gay et al. (23) had lower prevalence values, 52.8 % and 38% respectively.
When examining external apical root resorption, a measure to evaluate the quantity of root resorption present after the treatment, the results found are in different values. In the study by Liu et al. (46) resorption values were in terms of percentage volume loss, all around 7 and 8 %, whilst in the study by Gandhi et al. (47), the EARR was determined in terms of mm lost, 0.47 and 0.41 mm, in maxillary central and lateral incisors.

CONCLUSION

In this systematized review, a number of limitations were present. The principal limitation was the limited number of studies for the objectives and the small sample size of most studies used. In addition, there were large differences in methodologies among the study: namely only two studies (31,39) used cone beam technology to analyse tooth movement predictability, the rest superimposing only digital scans. Moreover, the methods used to analyse tooth movement differed largely among the studies, as outlined previously.

Based on these limitations, the conclusions based on the objectives were the following:

1) Regarding crown movements' predictability with Invisalign®, extrusion movements seem to be more predictable than intrusion movements. Similarly, tipping movements are more predictable than rotation movements. Tipping seems to be the most predictable of all crown movements.
2) Root movements' predictability is less predictable than crown movements and translation movements seem to be more predictable than torque movements. Lingual torque seems to be easier to execute than vestibular torque.
3) Invisalign® optimized attachments and Power ridges® do not seem to have a significant effect on movements' predictability compared to other attachments used. Only in mandibular incisors' extrusion, optimized attachments seem to have a significant influence on the predictability of the movement.
4) At the end of an Invisalign® treatment, incisors' root resorption does seem to occur with a prevalence ranging from 100% to 38%. However, the amount of root resorption is extremely small, representing about 8% of the incisor's root volume on average.

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