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ACCURACY AND EFFECTIVENESS OF CLEAR ALIGNERS IN ANTERIOR TEETH MOVEMENTS: A SYSTEMATIC REVIEW

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ABBREBIATIONS

TP: Tooth Positioner

IPR: Interproximal Reduction

PR: Power Ridge

CAT: Clear Aligner Therapy

CAD: Computer-Aided Design

CAM: Computer-Aided Manufacturing

3D: Three-dimensional

PVS: Polyvinyl Siloxane

Mx: Maxillary

Mdb: Mandibular

Mvmt: Movement

I: Incisive

CI: Central Incisive

LI: Lateral Incisive

C: Canine

ABSTRACT

Introduction: Nowadays more adults want to improve their smile and some of them expect something more comfortable and more aesthetic, such as clear aligners. However, certain dental movements can be particularly difficult to control.

Objectives: To analyze the use of clear aligners for anterior teeth movements in adults, analyzing the outcome of the different types of movements using aligners (intrusion, extrusion, rotation, inclination, torque and translation or bodily movement) in the anterior sector (canine to canine), and comparing the outcome of the different types of movements in the maxilla and in the mandible.

Material and Methods: For this systematic review, we used PRISMA guidelines. We searched on December 2021 on MEDLINE and Scopus databases for studies published between 2001 and 2021. All clinical trials about anterior teeth movement in adults were included, without language restriction. We excluded reviews and all other designs that were not clinical trials, studies who did not fulfilled the inclusion criteria, papers without significant results and in vitro studies. The quality of the evidence was assessed with the QUADAS-2 risk of bias tool.

Results: From 414 records found in databases searching, 9 relevant articles were selected (7 retrospective and 2 prospective), all of which had a low or unclear risk of overall bias. A total number of 295 patients (189 women and 106 men) were included. According to the literature, rounded teeth were the more difficult to rotate. About vertical movements, intrusion was defined as an inaccurate movement (44.5%), and extrusion as the least accurate tooth movement (29.6%). Two types of tipping were assessed, mesio-distal tipping (55.5%) and vestibulo-lingual/palatal tipping (56%), they were the most accurate type of movement for anterior teeth. For translation, not enough studies were included to assess accurate results. About incisive torque, it was a complex movement to perform (38.1%).

Conclusions: Despite the limitations, this systematic review suggests that clear aligners can produce all types of anterior tooth movements with a variable predictability and accuracy. No statistical difference between achieved and predicted anterior tooth movement was found when comparing the same movement applied to the same tooth but in different arches.

KEY WORDS

Clear aligner therapy; Invisalign®; Orthodontics; Invisible orthodontics; Aesthetic appliances.

1. INTRODUCTION

In recent years, an increasing number of adult patients are looking for improving their smiles. However, they desire an alternative to conventional orthodontic appliances, something more comfortable and more aesthetic, such as clear aligners. Clear aligner technology represents a transformational revolutionary change in orthodontics that challenges thinking about how orthodontists move teeth. However, the advent of clear aligner technology does not mean that 150 years of orthodontic principles are no longer valid (1). Clear aligners could be the future of orthodontics.

1.1. History

We might mistakenly think that orthodontic splint treatments are a recent invention, nevertheless, as early as 1923, Remensnyder introduced “the Flex-O-Tite”, a gum-massaging appliance for the treatment of pyorrhoea. He demonstrated a subsidiary effect by observing minor dental displacements secondary to wearing this appliance (2).

The proper clear aligners’ history in Orthodontics may be traced back to 1945, when Dr H. D. Kesling first proposed a clear, vacuum-formed tooth-positioning appliance (1), known as the Tooth Positioner (TP) (3). He manufactured a rubber device, designed from a set-up where the teeth were placed in the desired position using laboratory wax in order to refine the final stages of orthodontic treatment, allowing minor tooth movements while maintaining alignment of the remaining teeth in the arch. He recognized the limits of this technique, but he nevertheless envisaged the realization of movements of greater magnitude: “‘Major tooth movements could be accomplished with a series of positioners by changing the teeth on the set-up slightly as treatment progresses. At present, this type of treatment does not seem to be practical. It remains a possibility, however, and the technique for its practical application might be developed in the future" (4).

Almost 20 years later, in 1964, Nahoum published an article in which he described an appliance formed under vacuum from a set up: "Dental Contour Appliance". It was used to treat larger malocclusions, such as space closures or slight rotations (5).

Thirty years after the creation of the TP, in 1971, Ponitz introduced a similar device called the “Invisible Retainer”. It produced tooth movement and obtained its results, just like the Kesling ‘s appliance, thanks to the tipping of crowns (5).

In 1985, MacNamara refined Ponitz’s technique for fabricating invisible retainers. He reported good results for the displacement of the incisors, canines, and premolars but difficulties in moving the molars. When used as retainers after the treatment with conventional brackets, they have their advantages but do not have the same long-term durability of traditional acrylic or bonded retainers (2).

In the early 1990’s, Sheridan introduced his variation of to the family of thermoplastic appliances, “the Essix Retainer” consisting in the use of clear aligners in combination with interproximal enamel reduction. The goal was, as for its predecessors, to produce small tooth movements (5).

Since decades, Clear Aligner Therapy (CAT) had been a small part of orthodontic practice but in 1997, two graduate students at Stanford University applied three-dimensional (3D) computer imaging graphics to the field of orthodontics and created the world’s first mass-produced, customized clear aligner system (1) making possible the increasing popularity of the technique. They established Align technology® and release their Invisalign® system (3).

1.2. Design

The aligners are made of thin, transparent plastic that fits over the buccal, lingual/palatal and occlusal surfaces of the teeth.

Parameters that influence the biomechanical characteristics of aligners include the properties of the material, the thickness of the material, and the fitting accuracy of the aligner to the teeth and any attachments (3).

These attachments are a non-negligible part of treatment with aligners when talking about retention (6).

Each aligner system has its own means to facilitate dental movements and to control different movements such as rotations or even the dental axis during space closure. Therefore, the shape and size of these attachments vary depending on the desired tooth movement and must be elected with precision (5).

Ellipsoid attachments were the first to appear with Invisalign®. They are indicated for dental extrusions when used in a horizontal position on the incisors for anterior open bite closures or for retention of the splint when used in a vertical position on the first premolars (2). They can be 3 mm high, 2 mm wide and 0.75-1 mm thick and are available for incisors, canines and premolars (4).

Rectangular attachments are specified for large mesio-distal bodily tooth movements and provide larger area for force application. They can be placed vertically or horizontally. When they are used on buccal and lingual surfaces, extrusion and rotation movements and arch leveling can be achieved (6). They can be 3, 4 or 5 mm high, 2 mm wide and 0.5-1 mm thick (4).

Beveled rectangular attachments have the same dimensions as rectangular attachments but they are horizontally beveled towards occlusal/incisal or gingival, or vertically beveled towards mesial or distal, and are used to achieved extrusion and to prevent slipping. They can be 3, 4 or 5 mm wide, 2 mm high and 0.25-1.25 mm thick (4).

Since 2010, the innovations Smartforce^{TM} and Power ridge^{TM} allow to establish custom attachments adapted to the dental morphology and the desired movement and permit the improvement, the control and the precision of movements. For instance, the precision attachments for rotations, for the control of the root axis of the maxillary central incisors and canines, and for the maxillary lateral incisors for simultaneous movements in the different spaces's planes (2).

An alternative of the aligner surface designed is the Align Technology's Power Ridge. It is used to maintain a perfect fit of the aligner at the gingival margin, controlling the force couple and effectively spinning the tooth around its center of resistance (7).

When it comes to tooth alignment, interproximal reduction (IPR) is one option for resolving crowding. It is a therapeutic technique that involves the reduction, anatomic recontouring, and protection of the interproximal enamel surfaces of permanent teeth in order to gain space and align teeth (8).
The clinician can prescribe anterior IPR and/or in the right and left posterior portions. IPR should be assessed in terms of quantity, location, and timing (1).

The quantity of IPR in the ClinCheck® plan should be evaluated to see if it is appropriate for crowding resolution however it must not exceed 1 mm at each contact point. associated dark triangles between teeth Making a treatment plan with little IPR may be preferable in younger patients. More IPR may be given for elderly individuals with triangular-shaped teeth (1).

For a IPR between 0.1 and 0.3 mm, abrasive strips or diamond discs with one or two abrasive faces can be used, with a small diameter for the mandibular teeth and a larger diameter for the maxillary teeth. Between 0.3 and 0.6 mm, turbine burs from the Sheridan kit can be used. In case of a difficult access, WH "mini-saw" strippers mounted on a SYNEA WH contra-angle enable to follow the teeth' contour (2,9).

1.3. Aligner systems

Today, it exists a lot of aligner systems, a lot of different brands, and the most known is Invisalign®. All of them are using similar principles to achieve their results (5). For instance, one of the biggest contestants of Invisalign® appeared in 2006, it is called Orthocaps®. It takes up the concept of Invisalign® with some modifications, like the use of softer aligners to apply lighter forces and obtain better treatment finishes. The ***Table 1a*** is a non-exhaustive list of current aligner systems available.

Table 1a. *Types of Aligner systems currently on the market.*

Name of appliance	Website
AirNivol®	www.airnivol.com
Clear Aligner®	www.ca-clear-aligner.com
ClearStep®	www.crescentdental.co.uk
Dentosmile aligner®	www.biotech-dental.com
Ealigner®	www.ealigner.com
Essix®	www.essix.com
Essix PLUS®	www.essix.com
Franksmile®	www.franksmile.fr
Harmonieschiene®	www.harmonieschiene.de
Invisalign®	www.invisalign.fr
Originator®	www.tportho.com
Orthocaps®	www.orthocaps.fr
Simpli5®	www.ormco.com
Smilers®	www.smilers.com

1.4. Invisalign®

When it appeared, Invisalign® was defined as a new method of straightening teeth without braces (10) and was the first appliance in orthodontics to use computer-aided design (CAD) and computer-aided manufacturing (CAM) (5). This technique is used to set up tailored aligners from a very accurate impression or an intraoral 3D image scanned in the dental office. Instead of requiring a new impression for each tooth movement, this technology allows for multiple tooth set-ups to be created from a single impression, replicating the patient's teeth as a 3D model (11). The advent of this digital process removed the impracticality of previous aligner systems and made Kesling's concept a reality (5).

1.4.1. Six-step process

Before starting with the treatment, all necessary basic restorative treatments must be completed, the patient must be free of any active periodontal disease and must have his second molars fully erupted. The full process includes six different steps.

Step 1: Patient records, diagnosis, treatment plan submission.
First, the practitioner conducts a clinical and radiological examination of the patient to assess his orthodontic needs.
It is essential to take high quality pre-treatment records such as study models, panoramic x-ray and a lateral teleradiograph, to establish a correct diagnosis on the skeletal, alveolar, and dental level, in the transverse, vertical and sagittal directions (2).
As well, some photographs must be taken. The software ClinCheck Pro® informs the clinician that eight photographs are required for the future submission (***Table 1b***) (12).

Table 1b. *Photographs needed for submission.*

Extraoral photographs	Intraoral photographs
Frontal smiling	Anterior
Frontal repose	Right and left buccal
Lateral profile repose	Maxillary and mandibular oclusal

Also, it is very important to take good original Polyvinyl Siloxane (PVS) upper and lower impressions, if the clinician does not have an iTero® scanner. In this case, a scan of the mouth will replace the impressions. All the processing will be based on the impressions: it is therefore extremely important to pay particular attention during their realization and to demand a high quality (2).
Finally, he must also assess the psychological background and motivation of the patient and once all the diagnosis has been performed, he can inform the patient of the various therapeutic possibilities, establishes an estimate, and then start the treatment after having obtained the informed consent of the patient (13).

Step 2: Records submission.

For the correct submission to Align Technology®, some records must be sent: the impressions and an original PVS bite registration (or the scanned files that replace them), the eight photographs and a prescription form. The company provides prepaid mailing boxes when the clinician needs them.

At this stage, the practitioner disposes of three treatment options when talking about adult patients.

The first one is the most traditional one, the “Full” option, used to treat the full arch.

The second option is the 3/3, the “Anterior Prescription and Diagnostic form”, used to treat the anterior sector only, from canine to canine.

Finally, the third and last one, the “Invisalign® Express Form”, used to treat only minor cases using as a maximum ten aligners (12).

Step 3: 3D computer modelling.

When the clinician doesn’t have a scanner in his dental office. During this step, Align Technology® transforms the patient’s PVS impression into 3D images to obtain a 3D computer graphic image of all the teeth and tissues (12).

Step 4: ClinCheck®.

ClinCheck® is a 3D representation of the planned orthodontic teeth movements. It provides the basis for any interaction between the orthodontist and Invisalign® and is the starting point for assessment by the orthodontist in terms of individual treatment steps to be implemented in the aligner and virtual set-up of the treatment goal (14). It is used to check the concordance between the virtual and the real occlusion from all perspectives. Once prepared, it is sent to the practitioner to visualize the initial simulation of the treatment in 3D computer graphics, step by step. The doctor can review the ClinCheck® and confirm it if he agrees. He must validate the following points (12):

- The final position of the teeth.
- The interproximal reduction (IPR).
- The treatment staging.
- The attachments and pontics.

- The overcorrection.

Step 5: Manufacturing of aligners, initiation of treatment, aligners delivery.

Once the treatment plan has been approved by the doctor, the aligners will be manufactured using the sequence of graphical images combined with CAD/CAM. Within 10 days, the practitioner receives the aligners in his office.

If attachments are necessary, they are placed first and then the aligners are delivered to the patient with a starter kit and the doctor will provide written and verbal instructions. The patient must wear each set of aligners for two weeks (or the time that the doctor deems appropriate), full time, except for eating, drinking, and brushing his teeth, until the end of the treatment (12).

The aligners must be worn for a minimum of 20 hours per day and are changed (and advanced) on a 1 or 2-weekly basis. However, the wearing time of each splint can differ depending on the system used.

Each aligner is designed to move a tooth or small group of teeth about 0.25–0.3 mm every 14 days (13).

Step 6: Treatment monitoring, midcourse correction, refinements, retention.

Careful treatment monitoring is carried out every six to eight weeks to verify the correct fit of the aligners, the evolution of the treatment and to identify problems. Sometimes, changes during treatment or "midcourse corrections" are necessary, for instance, when the adaptation of a splint is not satisfactory. Additional gutters may be necessary for finishing. This is called a “refinement”.

When the treatment has been completed, the patient goes into retention. Most often, a removable retainer (the last aligner of the treatment, or a new thinner retainer) is worn day and night for six months and then at night only for an indefinite period (12).

1.4.2. Advantages

CAT offers certain advantages that traditional fixed appliance orthodontic treatments might not have.

Aesthetics: Patients who request CAT have been shown to have aesthetic concerns as a primary motive (3). The aligners are relatively invisible, it makes them the biggest draw card for the patient, mainly when talking about adults, seeking orthodontic correction (13).

Ease of use for the patient: The aligners are simple to insert and remove, it can be done unobtrusively and out of sight (13).

Comfort: The aligners are custom-made and therefore integrate naturally into the environment of the lips, cheeks, and tongue (2).
At first speech can be affected, it requires a slight adaptation time. The discomfort is transitory lasting usually for around 24 hours (13). In addition, this alteration affects 50% of patients, the other 50% do not encounter any difficulty to speak (2).

Care and oral hygiene: The aligners do not require any particular care. Brushing with a toothbrush and toothpaste at tooth cleaning times is all that is needed. Because there is no equipment in place while cleaning is done, dental hygiene is considerably easier for the patient, resulting in significantly better oral health throughout treatment. This is particularly important for periodontally compromised patients (13).

Periodontal health: CAT has been recommended for consideration in treatment planning adult orthodontic patients at risk of periodontitis. When compared to fixed buccal orthodontic appliances, CAT was found to be related with improved periodontal condition and lower levels of periodontopathic bacteria over a 12-month trial period (3).

Less emergencies in the dental office: A study by Buschang et al. in 2015 (15) on efficiency, confirmed the advantages of minimal patient emergencies with CAT, clear aligners are made of a high-quality plastic and CAT stands out for lesser use of auxiliary parts, such as bands or wires, easily broken or damaged and therefore mainly responsible for emergency visits. They are also removed during eating, unlike braces, reducing the risk of breaking during mastication.

1.4.3. Disadvantages

Even it exists many advantages to the use of clear aligners, certain disadvantages must be considered.

Removable: The clear aligners are removable appliance that must be worn diligently and changed regularly for the treatment to work. The success of the treatment depends on the patient collaboration and education. It is important for the patient to be involved in his treatment and the practician must educate the patient correctly about the respect of the wearing time, the regular change of the aligners without skipping the steps, and the need to go to the end of the treatment for the results to be stable and permanent. If the patient is not following all the indications the treatment will not succeed (2,16).

Lack of practitioner control: The aligners are made in total, from treatment start to treatment completion. It means that after the dentist validates the treatment plan, he has no ability to alter the appliance during treatment.
Treatment goals and results must be thought out from the start and cannot be changed. If the treatment does not go as planned, new impressions are needed and the case is ‘rebooted’ through the ClinCheck® mechanism, which is cumbersome and expensive (13,16).

Cost: The treatment with aligners includes some laboratory costs and the dentist’s fees. Both combined, the whole price of the treatment is generally between 4500€ and 6000€, that is considered as an expensive treatment for the patient.

Effectiveness and recurrence: Some studies demonstrated that treatments with clear aligners get the tendency to be less effective than other treatment as brackets for instance. Also, according to Kuncio, it appears to recur more than fixed treatments (17).

2. JUSTIFICATION, HYPOTHESIS AND OBJECTIVES

Day after day, more adults want to improve their smile and some of them expect an alternative to conventional orthodontic appliances. They desire something more comfortable and more aesthetic, such as clear aligners. That's the reason why this present systematic review is done, to update the knowledge about effectiveness of CAT in controlling the orthodontic anterior movements in adults, in order to help the practicians with this technique.

According to the literature (17), certain dental movements are particularly difficult to control, and with this study we are going to analyse the accuracy of different types of movement done with clear aligners in the anterior sector.

Evidence has been reviewed for dental movement with Invisalign some years ago (18–21), but with all the changes and progress made day after day in the field of clear aligners, we wanted to analyse the accuracy of these ones by considering the latest studies carried out in order to update the information if changes have been demonstrated.

The hypothesis of this work is that the clear aligners are effective in the treatment of the dental malocclusions.

The main objective of this review is to analyse the use of clear aligners for anterior teeth movements in adults.

The specific objectives are:

1) To analyse the outcome of the different types of movements using aligners (intrusion, extrusion, rotation, inclination, torque and translation or bodily movement) in the anterior sector (canine to canine).
2) To compare the outcome of the different types of movements in the maxilla and in the mandible.

3. MATERIAL AND METHODS

This review was planned, conducted, and reported in adherence to PRISMA standards of quality for reporting systematic reviews (22) (Appendix 1).

In Appendix 2 is included the format article of this work.

3.1. Eligibility criteria

3.1.1. Pico investigation

We used two different databases, MEDLINE and Scopus, to find articles published until December 2021 and studying the accuracy and effectiveness of clear aligners in anterior teeth movements with the purpose to answer the following question: *In adults, is the use of aligners accurate when talking of anterior teeth movements?*

The “PICO” approach was used to extract data from the selected articles. PICOS stands for:

1) **Population** (participants): We included studies on adult (age ≥18 years of age) patients.
2) **Intervention**: We considered patients treated with Invisalign treatment.
3) **Comparator**: None.
4) **Outcomes**: To be included, a study had to use a defined clinical outcome relating to efficacy of anterior teeth movement.

3.1.2. Inclusion and exclusion criteria

To be included in the review, the studies had to be clinical trials and meet all the following criteria: published between 2001 and 2021, because most studies about Invisalign were published more than ten years ago but we wanted

to actualise the previous investigations adding more recent one to reflect the current situation of CAT.
We excluded reviews and all other designs that were not clinical trials, studies who did not fulfilled the inclusion criteria, papers without significant results and in vitro studies.

The detailed inclusion and exclusion criteria for admittance in the systematic review are resumed in ***Table 2***.

Table 2. *Table resuming the inclusion and exclusion criteria.*

Inclusion criteria	Exclusion criteria
Studies on Humans	
Studies published between 2001-2021	
Clinical trials in adults (≥ 18 years)	
Articles about anterior teeth movements	Articles without significant results
Studies about intrusion, extrusion, rotation, inclination, torque and translation.	Experimental in vitro studies Duplicate studies
Studies with adequate statistical analysis	
Any language	

3.2. Information sources

The search of the literature was performed on 27th December 2021, in order to retrieve lists of potential articles to be included in the review, using the 2 following biomedical databases previously cited: MEDLINE and Scopus.

3.3. Search strategy

Search terms were identified by looking at words in the titles, abstracts and subject indexing of some relevant studies about CAT and teeth movement effectiveness. Several draft search strategies were developed using those terms:

‘clear aligner therapy’, ‘Invisalign®’, ‘orthodontics’, ‘invisible orthodontics’, ‘aesthetic appliances’, ‘effectivity’, ‘accuracy’.

To obtain more accurate studies to include in our systematic review, we used the two Boolean Operators, AND and OR. For the search on MEDLINE search terms were identified and checked using the MEDLINE MeSH indexing.

Because of the differences in regulated vocabulary and syntax restrictions, detailed search algorithms were devised and suitably changed for each database.

The search was conducted on 27th December 2021, searching for articles published between 2001 and 2021, and using the terms “(MM "Orthodontic Appliances, Removable") AND ((accur*) OR (valid*) OR (reliab*) OR (effectiv*) OR (precis*))” on MEDLINE, and TITLE-ABS-KEY(Invisalign) AND ((accur*) OR (valid*) OR (reliab*) OR (effectiv*) OR (precis*)) on Scopus.

About the search in the database MEDLINE, 230 articles were found at first, without applying any exclusion or inclusion criteria. In the case of Scopus search, 184 were found (***Table 3***).

Table 3. *Table including for each database the terms used and the number of articles obtained for each one.*

Database	Search strategy	Articles
Scopus	TITLE-ABS-KEY(Invisalign) AND ((accur*) OR (valid*) OR (reliab*) OR (effectiv*) OR (precis*))	184
MEDLINE	(MM "Orthodontic Appliances, Removable") AND ((accur*) OR (valid*) OR (reliab*) OR (effectiv*) OR (precis*))	230

In addition, we hand-searched the reference lists of all included studies and previously published reviews and undertook forward citation tracking using

Google Scholar to identify further eligible studies or study reports. However, no extra articles that fulfilled inclusion criteria were found during these searches.

3.4. Selection process

Citations identified from the literature searches and reference list checking were imported to Mendeley and duplicates were removed.
The selection of the papers to include in the review has been realized in three phases.

During the first and second phases, two researchers (EP, PE) independently screened titles of all articles retrieved and then abstracts of the ones selected with titles, to make sure they were relevant according to the criteria of the study. In case of disagreement, consensus on which articles to screen full-text was reached by discussion.

Subsequently, for the third phase, studies that satisfied the eligibility criteria were included through full-text assessment. Again, in case of disagreement, consensus on which articles to include was reached by discussion.

If during any phase of the process the two researchers couldn't agree, a third researcher was consulted to make the final decision.

3.5. Data collection process

The data from eligible studies were collected by one reviewer (EP) and checked by a second one (PE). Extracted data were compared and discrepancies were resolved through discussion.
To download titles and abstracts from the search databases, Mendeley software (Elsevier Inc, NY, USA) was used.

3.6. Data items

The eligible outcome for this study was defined as "effectivity of anterior dental movement" in adults, comparing the predicted and the obtained post-treatment results for several types of movements.

Any measure of anterior dental movement accuracy was eligible for inclusion. No restrictions were placed on the treatment duration, but the type of teeth and the movement evaluated were considered when interpreting study findings and in deciding which outcomes were similar enough to combine for synthesis.

The data from the eligible research was then compiled into several tables (Appendix 3).

The first table (***Table 4***) describes the characteristics of the different studies included in this review and the following parameters: author detail, year, study design, sample characteristics, type/number of teeth, auxiliary elements, analysis methods, movement performed and outcome.

The second and third ones (***Tables 5* and *6***) reports the accuracy of different types of movement for maxillary/mandibular incisors and canines, including the upcoming parameters: author detail, year, study design, sample size, mean age, type of teeth, number of teeth, auxiliaries, and all types of movement (intrusion, extrusion, rotation, mesiodistal tip, vestibulolingual tip, torque and translation).

The following table (***Table 7***) relates the different global weighted averages of each type of movement, according to the same parameters as the two previous tables.

From the three previous tables, another one was made (***Table 8***). It presents the weighted averages for each type of movement in maxillary and mandibular teeth, incisors and canines, including the parameters: intrusion, extrusion, rotation, mesiodistal tip, vestibulolingual tip, torque and translation.

Finally, the subsequent one (***Table 9***) compares the accuracy of teeth depending on if they are superior of inferior teeth with these parameters: author details, year, study design, sample size, mean age, type of movement, type of teeth, maxilla and mandible.

The last one (***Table 10***), is derived from ***Table 9*** and describes the weighted averages of accuracy for maxillary and mandibular teeth according of the type of movement: intrusion, extrusion, rotation, mesiodistal tip, vestibulolingual tip, torque and translation.

In all eleven articles, the sample was composed of a different number of teeth, therefore, the weighted average was used to obtain more representative results (***Tables 8 and 10***). In some studies, the weighted average was already calculated, but in some cases, it was necessary to determine it. To do it, the number of teeth of each study was divided by the total number of teeth of all studies and multiplied by the mean value reported by each study.
Three studies could not be included in the weighted average due to the type of unit used to describe the results (degrees or mm) that differed from the main one, percentage. Therefore, the results focused on a descriptive study of the variables.

3.7. Study risk of bias assessment

The methodological quality of the studies was determined using the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies-2) tool (23). According to the applicability of the studies, four domains were evaluated to determine the risk of bias and level of concern:

Patient selection: studies with a non-random or non-consecutive sample of patients, were deemed to have a high risk of bias.

Index test: it was rated as high risk of bias when diagnostic methods were used without knowing the results of the reference standard.

Reference standard: it was classified as high risk of bias when reference standards were conducted with knowledge of the index test results.

Flow and timing: they were assessed as having a high risk of bias when the reference standard was not applied on all patients or when all samples were not included in the study, or when a significant time had passed between the index test and the reference standard.

Concerns about the studies' applicability were assessed as follows:

Patient selection: studies with a small sample size (less than 15 patients) were defined as having a high risk of bias.

Index test: a high risk of bias was indicated when the index test implementation differed from the review question.

Reference standard: studies that didn’t use cast analysis and reliability evaluation to assess the validation of the target condition obtained a high risk of bias.

4. RESULTS

4.1. Study selection

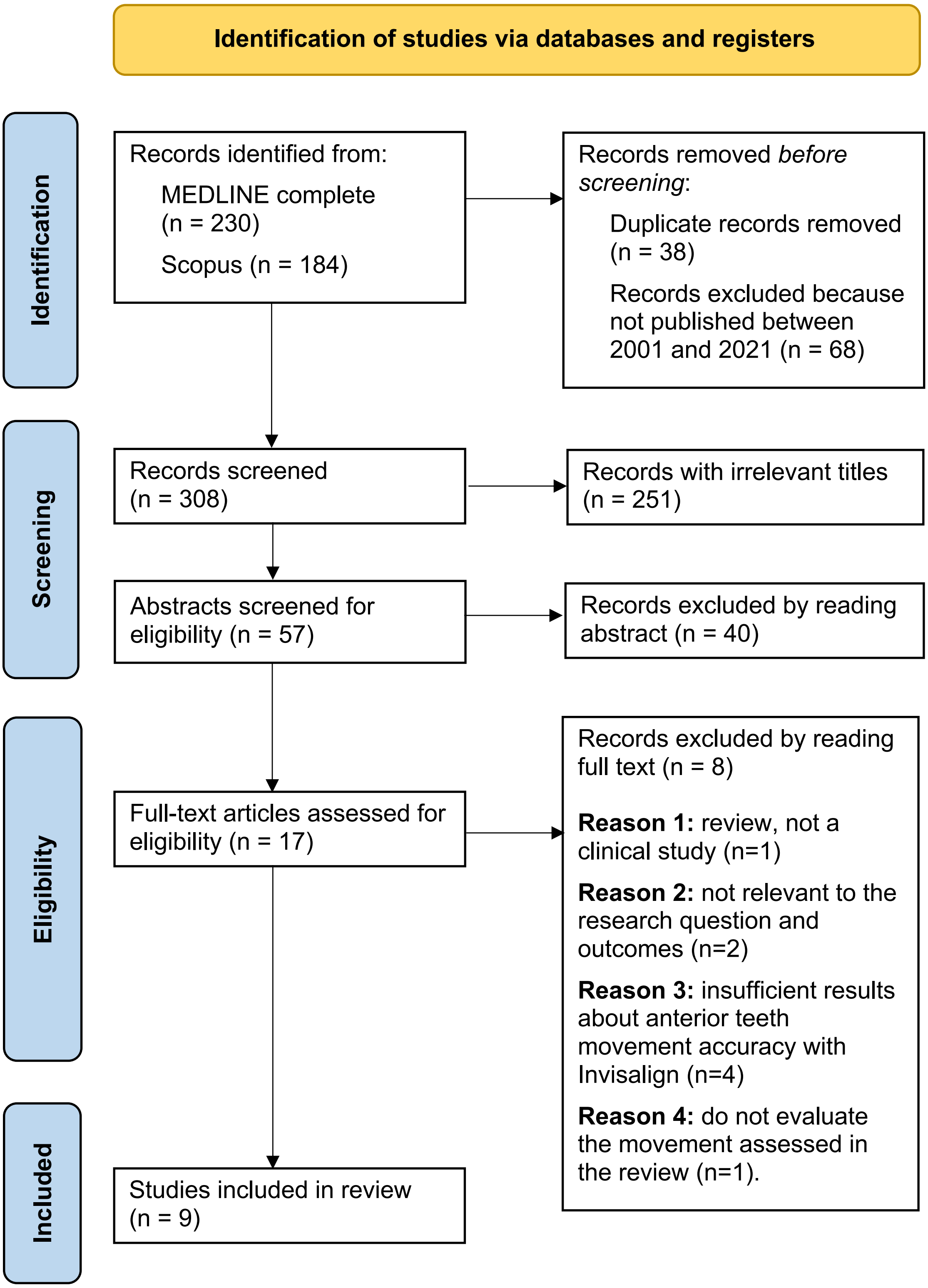
414 records were found in databases searching, 230 in MEDLINE complete and 184 in Scopus. From all these studies, 68 were excluded because they didn't fulfill the date inclusion criteria (published between 2001 and 2021). After duplicates removal, we screened 308 titles, from which we reviewed 57 abstracts and then 17 full-text documents. Finally, after the review of the 17 full-text documents, 8 studies were excluded, and the last 9 ones met the inclusion criteria and were included in this systematic review (10,11,24–30). The article selection process is illustrated in the PRISMA Flow Diagram (***Figure 1***).

From the 8 articles we excluded by the review of the full-text documents, 1 was excluded because of the format, reviews or not clinical studies, 4 had insufficient results about anterior teeth movement accuracy with Invisalign, 2 were not relevant to the research question and outcomes, and 1 did not evaluate the movement assessed in the review. The reasons for their exclusion are resumed in ***Table 11***.

Table 11. *Characteristics of excluded studies.*

Study	Reason for exclusion
Hennessy et al. 2016 (31)	Insufficient results about anterior teeth movement accuracy with Invisalign.
Gu et al. 2017 (32)	Insufficient results about anterior teeth movement accuracy with Invisalign.
Krieger et al. 2011 (33)	Not relevant to the research question and outcomes.
Johal et al. 2021 (34)	Not a clinical trial.
Liu et al. 2021 (35)	Insufficient results about anterior teeth movement accuracy with Invisalign.
Long et al. 2020 (36)	Not relevant to the research question and outcomes.
Hahn et al. 2010 (37)	Insufficient results about anterior teeth movement accuracy with Invisalign.
Krieger et al. 2012 (14)	Do not evaluate the movements assessed in the review.

Figure 1. *Flowchart.*



4.2. Study characteristics

Of the 9 relevant studies identified, 7 studies were retrospective (10,11,26–30), and 2 studies were prospective (24,25). Including all the studies reviewed, the sample size ranged from 16 to 69, with a total number of 295 patients. Regarding the gender distribution of the 285 patients, 189 were women and 106 were men.

About the type of clear aligners used, Invisalign® was used in all studies except for one that realized its research with F22 aligners.

Categorizing each type of movement reviewed in this review, 5 studies evaluated rotation (10,24,25,27,28). According to vertical movements, 3 studies considered intrusion (10,11,25) versus 2 for extrusion (10,25). Two types of tipping were assessed, mesio-distal tipping, by 3 studies (25,27,28), and vestibulo-lingual/palatal tipping, by 3 (25,28,29). Finally, 2 studies talked about translation movement (10,29) and 4 about incisive torque (26,27,29,30).

Regarding the use of auxiliaries such as attachments, PR and/or IPR, their utilization was unrestricted and was determined by the clinician's therapeutic decision in 4 studies (10,25,27,28). In 3 studies, different subgroups of patients either with attachments, IPR, PR, a combination or none were described (11,24,26). Finally, 1 study didn’t have any precision about the use of these auxiliaries (29) and 1 had as an exclusion criterion the use of IPR (30).

Table 4 (Appendix 3) displays for each included study the author detail, year, study design, sample characteristics, type/number of teeth, auxiliary elements analysis methods, movement performed, and outcome assessed.

		Kravitz et al. 2008 (24)	Kravitz et al. 2009 (25)	Simon et al. 2014 (26)	Grünheid et al. 2017 (27)	Lombardo et al. 2017 (28)	Charalampakis et al. 2018 (10)	Jiang et al. 2021 (29)	Al-balaa et al. 2021 (11)	Gaddam et al. 2021 (30)	Total
Study design	Prospective	1	1	0	0	0	0	0	0	0	2
	Retrospective	0	0	1	1	1	1	1	1	1	8
N° of patients		31	37	30	30	16	20	69	22	40	295
Gender	F	18	23	19	17	10	17	44	12	29	189
	M	13	14	11	13	6	3	25	10	11	106
Type of movement	Intrusion	0	1	0	0	0	1	0	1	0	3
	Extrusion	0	1	0	0	0	1	0	0	0	2
	Rotation	1	1	0	1	1	1	0	0	0	5
	Translation	0	0	0	0	0	1	1	0	0	2
	Torque	0	0	1	1	0	0	1	0	1	4
	MD tipping	0	1	0	1	1	0	0	0	0	3
	VL tipping	0	1	0	0	1	0	1	0	0	3
Comparison mx VS mdb		1	1	0	0	1	0	1	0	0	4

F, Female; M, Male; MD, mesiodistal; VL, vestibulolingual; mx, maxilla; mdb, mandible.

4.3. Risk of bias in studies

The overall risk of bias was rated as unclear in five out of nine studies (Simon et al. 2014; Lombardo et al. 2017; Charalampakis et al. 2018; Al-balaa et al. 2021; Gaddam et al. 2021) and as low in four studies (Kravitz et al. 2008; Kravitz et al. 2009; Grünheid et al. 2017; Jiang et al. 2021).

Patient selection, index test, and reference standard were the primary domains that contributed to an unclear risk of bias. In the studies with an unclear risk of bias, this was owing to non-random or non-consecutive patient selection, with no reporting of patient recruiting details. The level of recording for the latter two domains was determined by an appropriate description of whether the diagnostic procedures were interpreted blindly and independently, without prior knowledge of the other tests (***Table 12***).

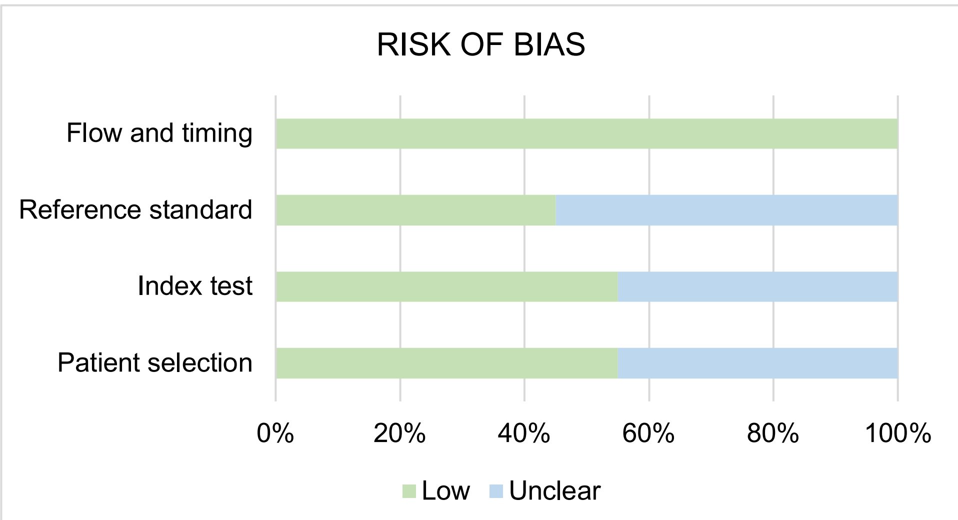
The percentage distribution of the risk of bias across domain of the QUADAS-2 tool is presented in ***Figure 2***.

Table 12. *Risk of bias assessment and applicability concerns (QUADAS-2).*

Study	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Kravitz et al. 2008 (24)	☺	☺	☺	☺	☺	☺	☺
Kravitz et al. 2009 (25)	☺	☺	☺	☺	☺	☺	☺
Simon et al. 2014 (26)	☺	?	?	☺	☺	☺	☺
Grünheid et al. 2017 (27)	☺	☺	☺	☺	☺	☺	☺
Lombardo et al. 2017 (28)	?	?	?	☺	☺	☺	☺
Charalampakis et al. 2018 (10)	?	?	?	☺	☺	☺	☺
Jiang et al. 2021 (29)	☺	☺	☺	☺	☺	☺	☺
Al-balaa et al. 2021 (11)	?	?	?	☺	☺	☺	☺
Gaddam et al. 2021 (30)	?	☺	?	☺	☺	☺	☺

☺ Low ☹ High ? Unclear

Figure 2. *Risk of bias assessment as percentage for domains.*



4.4. Results of individual studies

4.4.1. Accuracy of each type of movement

All nine studies (10,11,24–30) selected for this review can be used to analyse the outcome of the different types of movements using aligners (intrusion, extrusion, rotation, inclination, torque and translation or bodily movement) in the anterior sector (canine to canine).

Regarding **intrusion**, 3 studies provided data on accuracy of movement (10,11,25). The mean accuracy of intrusion was 44.5% with a range of 41.3% (25) to 48.8% (11).
Charalampakis et al. (10) defined the intrusion of incisors as the most inaccurate of all linear movements, with a difference of 1.5 mm between the predicted and the actual outcome for the maxillary central incisors, and a difference of 1.1 mm for the maxillary lateral incisors.
Similar results were achieved by Al-balaa et al. (11), who demonstrated that the predicted intrusion movement of the teeth significantly differed from the actual values ranging from 44.7% to 58.1%.
Kravitz et al. (25) found the highest accuracy of intrusion for the maxillary (44.7%) and mandibular (46.6%) central incisors. The lowest accuracy of intrusion in his study was attributed to the maxillary lateral incisors (32.5%).

According to **extrusion** of anterior teeth, data on movement accuracy was gathered through 2 studies (10,25). Extrusion was the least accurate tooth movement achieved with aligners (29.6%), specifically extrusion of the upper (18.3%) and lower (24.5%) central incisors (25). The most accurate teeth when talking of extrusion was the maxillary canines (49.9%).
In Charalampakis' study (10), the achieved extrusion was often larger than predicted, even though the difference was not statistically significant. The most accurate movement was obtained for the vertical movement of canines (-0.10 mm), followed by the extrusion of maxillary lateral incisors (-0.25 mm), and both maxillary central incisors and mandibular incisors (-0.30 mm).

Next movement is **rotation** and was evaluated in 4 studies (10,24,25,28), with a mean accuracy of 47.6%, ranging between 35.8% (24) and 62.4% (28).
Kravitz et al. (24) only evaluated the rotation of 53 canines, assessing a mean accuracy for canine rotation of 35.8%.
In his other study (25), the accuracies of rotation for the maxillary (32.2%) and mandibular (29.1%) canines were significantly lower than that of the maxillary central incisors (54.2%), mandibular central incisors (48.8%), maxillary lateral incisors (43.4%). and mandibular lateral incisors (51.6%).
Lombardo et al. (28) demonstrated as well that the accuracy of rotation of the canine was the lowest, with the rotation of the lower canines defined as the least efficient movement (54.2%).
Charalampakis et al. (10) evaluated the difference between the predicted and the actual outcome (in degrees). All achieved rotations were significantly smaller than those predicted, with the maxillary canines exhibiting the greatest difference of 3.05°, followed by the mandibular canines (2.45°). For all upper and lower incisors, the difference achieved was similar, 1.85° for all lower incisors and upper lateral ones, and 2° for the upper central incisors.
Grünheid et al. (27) evaluated the final efficacy of Invisalign technology to achieve predicted tooth positions, determining if the final position of each tooth is more distal or mesial than the predicted one. He demonstrated that the rotation of rounded teeth (canines) was incomplete. Mandibular canines were placed 0.88° more distally than predicted and maxillary ones were 0.19° more distal as well. For incisors, all of them were more mesial than predicted, and even more the lateral ones compared to the central.

Another type of movement has been evaluated by 2 studies (10,29), **translation** or bodily or movement, finding a mean accuracy of 0.14 mm for Charalampakis and 49.5% for Jiang.
According the Charalampakis et al. (10), horizontal movements of all incisors seemed to be accurate, with small (0.20-0.25 mm) or insignificant differences between predicted and achieved amounts.
Jiang et al. (29) found similar results in each arch with a better one in the lower one for central incisors (58.0%) and lateral incisors (54.7%) compared to the maxilla incisors (43.2% and 39.9%).

Torque of incisors was evaluated in 4 studies (26,27,29,30). The mean accuracy of torque was 38.1% ranging between 35.2% (29) to 42.0% (26).
Simon et al. (26) found a mean accuracy of 42% for torque of upper central incisors.
Jiang et al. (29) defined torque as the lowest accuracy achieved (35.2%). He evaluated the accuracy of both upper and lower incisors dividing them between upper central incisors (31.8%), upper lateral incisors (31.7%), lower central incisors (40.6%) and lower lateral incisors (37.2%). No significant difference was found between each type.
In his study, Gaddam et al. (30) evaluated the accuracy depending on the direction to move. Indeed, he divided the study on two groups, the labial crown torque group and the lingual/palatal crown torque group.
In the labial crown torque group, the difference between the predicted and achieved torque was statistically significant for the upper central incisor (6.43°), the upper lateral incisor (5.06°) and the lower incisors (2.75°). In contrast, for the lingual/palatal crown torque group, the difference was not statistically significant, but the results showed over-expression in upper central incisors (-0.73%) and lower incisors (-0.67%) sub-groups.
Finally, Grünheid et al. (27) evaluated if the final crown torque was more lingual or buccal than the predicted tooth position. For all lower anterior teeth, central incisors (-0.66°), lateral incisors (-0.29°), canines (-1.60°), and the upper canines (-0.48°), there was more buccal crown torque than predicted. In contrast, for upper central (+1.75°) and lateral (+0.08°) the final crown torque was more lingual.

Mesiodistal tipping was assessed in 3 studies (25,27,28) and the mean accuracy was 55.5%, ranging from 40.5% (25) to 82.1% (28).
Kravitz et al. (25) assessed that the less accurate tipping movement was the mesiodistal one and more precisely the one of the canines, both upper (35.5%) and lower (26.9%). Additionally, apart from the mandibular canine, no tooth was significantly less accurate in tipping movement, all of them add more or less the same accuracy, ranging between 35.5% to 48.6%.
In the F22 aligners study (28), the most accurate movement achieved was mesiodistal tipping, whose mean accuracy was 82.1%. The most precise

movement was achieved by lower incisors (87.7%) followed by the lower canines (86.7%).

Finally, Grünheid et al. (27) evaluated if the final achieved tooth position was more distal or mesial than the predicted tooth position. All anterior teeth had a more distal position than predicted, ranging from +0.51 mm to +0.31 mm, except the mandibular central incisor that was more mesial (-0.36 mm).

The last type of movement is **vestibulolingual tipping** and was evaluated in 3 studies (25,28,29).

Kravitz et al. (25) assessed a similar accuracy for all anterior teeth for vestibulolingual tipping, ranging between 40.3% to 47.6%.

In the F22 aligners study (28), the least accurate movement was vestibulolingual tipping of upper canines (54.0%).

Finally, Jiang et al. (29) evaluated the accuracy of vestibulolingual tipping of incisors and demonstrated that pure tipping (72.5%) was more predictable than controlled tipping (65.2%).

All the data about the accuracy of the different types of movements using aligners in the anterior sector are presented in ***Tables 5, 6, 7*** (Appendix 3) ***and 8***.

Table 8. *Weighted average for each type of movement in maxillary and mandibular teeth*

		Intrusion (%)	Extrusion (%)	Rotation (%)	Translation (%)	Torque (%)	MD tipping (%)	VL tipping (%)
Mx	I	46.1	24.9	52.2	41.9	37.5	53.9	53.6
	C	43.2	49.9	39,9	-	-	56.3	47.8
Mdb	I	43.9	25.5	55.1	56.3	39.0	56.7	62.1
	C	44.1	30.4	35,9	-	-	55.2	50.7
TOTAL		44.5	29.6	47.6	49.5	38.1	55.5	56.0

I, Incisive; C, Canine; MD, mesiodistal; VL, vestibulolingual; Mx, Maxilla; Mdb, Mandible.

4.4.2. *Maxilla VS mandible*

4 out of the 9 studies (24,25,28,29) can be used to analyze the outcome of the different types of movements in the maxilla and in the mandible.

When talking about vertical movements, **intrusion** and **extrusion**, Kravitz et al. (25) found similar results in both maxilla and mandible for all anterior teeth. Indeed, when evaluating predicted and actual outcomes for intrusion, in both superior and inferior maxilla, the accuracy of movement was respectively, 44.7% and 46.6% for central incisors, 32.5% and 40.0% for lateral incisors and 40.0% and 39.5% for canines.

All three studies (24,25,28) found no statistically significant difference in accuracy of **rotation** for maxillary and mandibular canines. Each of them found respectively 36.2% and 35.0%, 32.2% and 29.1%, and 62.3% and 54.2% as mean accuracies in maxilla and mandible. Indeed, the weighted average for the rotation accuracy of the maxillary canines (39.9%) and the mandibular canines (36.6%) were close to each other indicating to significant difference between the predicted outcome and the obtained one.
Lombardo et al. (28) found a similar conclusion for the rotation of incisives with a mean accuracy of 61.5% for the maxillary incisives and of 67% for the mandibular ones.

Only one study, Jiang et al. (29), evaluated **translation** and **torque** movement of incisives. Of these two types of movement, only translation showed a significant difference in efficacy between the maxillary and mandibular incisors. When comparing the difference between maxillary and mandibular arches, translation movement of the maxillary central and lateral incisors showed statistically less efficacy (43.2% and 39.9%) than that of the mandibular central and lateral incisors (58.0% and 54.7%).
No significant difference was found for torque of central and lateral incisives with a mean accuracy of 31.8% and 31.7% in maxilla, versus 40.6% and 37.2% in mandible.

About **mesiodistal tipping** of all three categories of anterior teeth, the weighted averages do not show significant differences in efficacy between the upper and lower teeth. Indeed, the weighted averages where 38.6%, 43.1% and 56.3% for either upper central incisives, lateral incisives and canines, versus 39.6%, 48.6% and 55.2% for the lower ones.

About mesio-distal tipping of canines, Kravitz et al. (25) found an accuracy of 35.5% in maxilla and 29.6% in mandible, whereas Lombardo (28) found higher accuracies, 78.3% and 86.7% for upper and lower arches respectively.

The same situation was obtained when talking about incisives. Kravitz et al. (25) found a mean accuracy of 38.6% and 43.1% for upper central and lateral incisives versus 39.6% and 48.6% for mandibular ones, and Lombardo et al. (28) found higher results, with an accuracy of movement for both upper and lower incisives (76.7% and 87.7%).

For the last type of movement reviewed, the **vestibulolingual tipping**, no significant difference in efficacy of the movement between the maxillary and mandibular anterior teeth was found for Kravitz et al. (25) and Jiang et al. (29). Indeed, Kravitz et al. (24) found for all upper central incisives, lateral incisives and canines, respectively, accuracies of 40.3%, 47.6% and 44.6%, and for the lower three types, 44.2%, 47.4% and 43.7%.

Jiang et al. (29) divided this type of tipping between controlled one and pure one. For both groups, no significant difference was found. The accuracy tipping for central incisives obtained was 65.40% and 77.2% with pure tipping for upper and lower arches, versus 64.8% and 66.7% with controlled one. About lateral incisives, the results obtained with pure tipping were respectively of 69.1% and 77.4% in maxilla and mandible, and of 62.7% and 66.8% in the controlled tipping group.

In the study of Lombardo et al. (28), the accuracy of movement of for both maxillary and mandibular incisives was different with a result of 64.5% for the upper ones, versus 86.1% for the lower ones.

As a summary, the weighted averages for vestibulolingual tipping are similar for maxillary central incisives (40.3%) and mandibular ones (44.2%), same situation for upper lateral incisives (47.6%) and lower ones (47.4%), and finally, for canines, no difference in accuracy was also found when comparing upper and lower ones (47.8% and 50.7%).

All the data about the accuracy of the different types of movements in the maxilla and in the mandible are presented in ***Table 9*** (Appendix 3) ***and 10***.

Table 10. *Weighted average.*

	Intrusion (%)		Extrusion (%)		Rotation (%)		Translation (%)		Torque (%)		MD tipping (%)		VL tipping (%)	
	Mx	Mdb	Mx	Mdb	Mx	Mdb	Mx	Mdb	Mx	Mdb	Mx	Mdb	Mx	Mdb
CI	44.7	46.6	18.3	24.5	-	-	43.2	58.0	31.8	40.6	38.6	39.6	40.3	44.2
LI	32.5	40.0	28.4	28.4	-	-	39.9	54.7	31.7	37.2	43.1	48.6	47.6	47.4
C	40	39.5	49.9	30.4	39.9	36.6	-	-	-	-	56.3	55.2	47.8	50.7

CI, Central Incisive; LI, Lateral Incisive; C, Canine; MD, mesiodistal; VL, vestibulolingual; Mx, Maxilla; Mdb, Mandible.

5. DISCUSSION

The aim of this study was to review literature dealing with the outcome of the different types of movements using aligners (intrusion, extrusion, rotation, inclination, torque and translation or bodily movement) considering the type of teeth from the anterior sector.

The search strategy and selection of studies resulted in nine studies. All of them were non-randomized clinical trials with unclear risk of bias in five out of nine studies (Simon et al. 2014; Lombardo et al. 2017; Charalampakis et al. 2018; Al-balaa et al. 2021; Gaddam et al. 2021) and with low risk of bias in the remaining four (Kravitz et al. 2008; Kravitz et al. 2009; Grünheid et al. 2017; Jiang et al. 2021).

This systematic literature study has identified evidence of the differences in accuracies depending on the type of movement performed on different teeth with CAT.

5.1. Accuracy of each type of movement

According to **intrusion** of anterior teeth, the three studies included in this review found similar results. Indeed, according to Charalampakis et al. (10), Al-balaa et al. (11), and Kravitz et al. (25), intrusion of anterior teeth is defined as an inaccurate movement.

Similar findings were found in a recent study made in 2020 by Haouili et al. (38). They demonstrated that incisor intrusion is a challenge and even more the accuracy of intrusion of the mandibular incisor (35%). One explanation for the lower accuracy of mandibular incisor intrusion may be the lack of posterior anchorage.

Another review (19), based only on one article, affirmed that CAT could be recommended for the treatment of simple malocclusions with light overbite discrepancies but not complex ones.

In sum, based on this literature, it has been demonstrated that anterior tooth intrusion is a challenging movement to produce with clear aligners and even over time the accuracy of this movement did not improve.

Extrusion seems to be one of the most critical movements to be carried out by means of aligners. However, when comparing the results of the two authors included in this literature, a difference can be noticed. As a matter of fact, in Charalampakis' study (10), the achieved extrusion was often larger than predicted, but with a difference not statistically significant. Moreover, extrusion of incisors appeared to be accurate, since no statistically significant differences were observed. On the other side, Kravitz et al. (25) found that only 13 of the 64 teeth had attempted extrusions greater than 1.0 mm, and no tooth had an attempted extrusion greater than 2 mm, with an average amount of extrusion of 0.56 mm.

Several authors in literature have highlighted this critical issue. In a previous review made in 2015 (19), similar results were found. It was demonstrated that CAT is not effective in controlling anterior extrusion movement of anterior teeth resulting in the fact that open bite is a challenging malocclusion to treat. Extrusion was the least accurate tooth movement achieved in this study (30% of predictability), with the lowest ones for the maxillary (18%) and the mandibular (25%) central incisors. This difficulty in performing extrusive movement can be explained thanks to the poor capacity of the aligner to grasp the tooth during vertical pull.

Later, in 2020, Haouili and al. (38) obtained a mean accuracy of 45.9% for tooth extrusion, showing an improvement of the performances of CAT. The use of optimized extrusion attachments could be a viable explanation for the improvement seen in this study.

When talking about **rotation**, all studies (10,24,25,28) found the same conclusions. Rounded teeth, mandibular and maxillary canines, are more difficult to rotate compared to incisors.

In one of his two studies (25), Kravitz et al. found that the accuracy of rotation of canine was smaller compared to incisors. They also indicated that the predictability of canine rotation was significantly decreased for movements greater than 15°. As well, Lombardo et al. (28) defined the rotation of canines as the least efficient movement in his study. In 2018, Charalampakis et al. (10) assessed that the difference between the predicted and the actual outcome of the maxillary canines was the greatest one, followed by the mandibular canines.

All these results are in line with a review realized in 2021 (39) that focused on the predictability of rotational tooth movement with orthodontic aligners. This review included 7 studies and concluded that the prediction of rotational tooth movements with aligners treatment does not appear accurate, especially for both maxillary and mandibular canines.
Another study made in 2020 (38) confirmed these findings but also took in consideration the direction of rotation because it influences the accuracy of the canine movement. It was found that distal rotation (37%) was significantly less accurate than mesial rotation (52%).
The results of these different studies suggest that tooth rotation with aligners are challenging movements, especially for rounded teeth, and it could be explained by the fact that cylindric teeth struggled to grip the aligners.

Only two studies evaluated **translation** of incisors (10,29). The translation of incisors was found to be accurate in Charalampakis et al. study (10), with small or insignificant differences between predicted and achieved amounts. Furthermore, Jiang et al. (29) expressed a difference between maxillary and mandibular incisors. No other reviews describing the translation of anterior teeth were found.

In this review, the mean accuracy of the **torque** of incisors found was small, indicating that it is a complex movement to realize. Indeed, Simon et al. (26) concluded that upper incisor torque is a challenging movement to perform with clear aligners, and that it is essential to take into account that overcorrections or case refinements may be needed, since the ClinCheck® simulation could predict more movement than what may result clinically.
As well, Grünheid et al. (27) assessed high discrepancies for the torque of upper central incisor and lower canines. Similar results were found in Jiang et al. study (29). Torque was defined as the lowest accuracy achieved.
In his study, Gaddam et al. (30) evaluated the accuracy depending on the direction to move. He expressed that incisor torque is under-expressed when incisors are programmed to move labially and over-expressed to a minor extent when incisors are programmed to move lingually, and that lower incisors demonstrated a more reliable expression of torque than the upper incisors. These

results suggest that the least accurate torque movements appear on the maxillary central incisor. This discrepancy found in the torque of maxillary central incisor was consistent with the observation made by other authors (40,41).

Based on the literature we used in this review, we can affirm that the **tipping** movements, both **mesiodistal** and **vestibulolingual**, realized with clear aligners are ones of the most predictable. Indeed, the results found by Lombardo (28) were in line with the one of Kravitz (25). In both studies, the upper canines tip was inaccurate, but with a higher accuracy in Lombardo study. Finally, in Grünheid et al. (27) no statistical significance difference was found. Similar results were found in this review for the vestibulolingual tipping if anterior teeth. Indeed, the mean accuracy of tipping of canines was slightly lower than incisors one. All these results were in line with a review made in 2015 (19) where it was demonstrated a scarce result in tipping canines. This suggest that teeth with larger roots might have greater difficulty achieving mesiodistal movements. These teeth have the longest roots in the dentition with large root surface areas, requiring greater force to produce orthodontic tooth movement (27).

5.2. Maxilla VS mandible

The findings about the accuracy of movement comparing maxillary and mandibulary teeth need to be interpreted with caution because of the small number of studies.

These findings indicated that no statistical significance difference was found for all types of movements when comparing the same movement for the same teeth in each arch. However, only a study (29) assessed a significance difference between the accuracy of translation of upper incisors and lower ones. The maxillary central and lateral incisors showed statistically less efficacy than the mandibular central and lateral incisors. As well, in the study of Lombardo et al. (28), the accuracy of vestibulolingual tipping for both maxillary and mandibular incisives was different with a lower efficiency of tipping for the upper ones compared to the lower ones.

These findings nonetheless appear to be largely in line with a recent study (38) were none of the anterior teeth expressed a statistically significant difference of movement accuracy between arches, but only the second molar and the second premolar when tipping was performed.

However, in a study published in 2021 (42), comparing achieved and predicted crown movement with Invisalign®, a significant difference was found about the accuracy of canine inclination when comparing the maxillary ones and the mandibulary ones. This may be explained by the realization of an extraction of the four first premolars before the realisation of the treatment with clear aligners.

5.3. Limitations of the study

The limitations of this study should be discussed in order to interpret the results correctly. Most of the limitations of this review are strictly related to the limitations of the included studies.

First, as within all systematic reviews, it is possible that we missed certain studies. We examined electronic databases and conducted a manual search, which may have limited the number of publications found and included in the review.

Second, the sample size of the included studies was generally small with the lack of proper blinding procedures and the absence of sample randomization procedures.

Third, in this review, the use of auxiliaries such as interproximal reduction, Power Ridge, or attachments was not considered when comparing the results. Indeed, the accuracy of the tooth movement may be influenced by interproximal reduction or attachments, but the evidence is unclear (26). In most of the studies, the supervising orthodontist was presumed to have had sufficient experience to prescribe them appropriately, and no restrictions were applied. Clearly, successful clear aligner treatment is not limited to aligners alone, and it is evident that the accuracy percentages we found could be improved in the hands of an expert orthodontist who has access to a full range of auxiliaries.

Fourth, the posterior teeth were not considered in this review. However, the movement of one anterior is not independent from the movement of adjacent or posterior teeth. The ideal way to overcome this limitation would be to include only reviews evaluating one type of movement of only one tooth in each patient, unfortunately, this would necessitate a large sample size or fewer variables.

Finally, in this review the benefits and the possible adverse effects associated with CAT were not evaluated, hence future studies could include them in the results to describe the accuracy of the treatment.
As well, much more parameters can influence tooth movement. It would be useful to explore and include the influence of other factors, such as the patient's age, sex, periodontal support, bone density or systemic factors, in future research.

Given the findings of this systematic review, it is suggested that future researchers in this field include randomized clinical trials with rigorous methodology and adequate sample size to increase the power of the studies in estimating the effects. Only with this knowledge will it be possible to develop specific CAT treatment protocols for use in daily clinical practice.

6. CONCLUSIONS

• Clear aligners can produce all types of anterior tooth movements with a variable predictability and accuracy. Vertical anterior movement are inaccurate, especially when talking of anterior extrusion movement. CAT is also not effective in controlling rotations of rounded teeth (canines). Not enough studies are made about translation in order to conclude an accurate result. About torque, it is a challenging movement to achieve with CAT, particularly for maxillary central incisor. Finally, tipping of anterior teeth is the most predictable movement to perform with CAT, but it appears more difficult for canines because of their larger root surface areas.

• No statistical difference between achieved and predicted anterior tooth movement was found when comparing the same movement applied to the same tooth but in different arches.

7. REFERENCES

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APPENDIX 1. PRISMA

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Front page
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	17
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	17
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	19-20
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	20
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	20-21
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	22
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	22
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	22-23
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	22-24
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	24-25
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	24
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	x
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	x
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	x
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	x
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	x
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	x
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	x
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	x

RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	27-28
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	27
Study characteristics	17	Cite each included study and present its characteristics.	29-30
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	30-31
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	32-38
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	x
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	x
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	x
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	x
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	x
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	x
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	39-43
	23b	Discuss any limitations of the evidence included in the review.	43-44
	23c	Discuss any limitations of the review processes used.	43-44
	23d	Discuss implications of the results for practice, policy, and future research.	44
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	x
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	x
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	x
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	x
Competing interests	26	Declare any competing interests of review authors.	x
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	x

APPENDIX 2. Article

ACCURACY AND EFFECTIVENESS OF CLEAR ALIGNERS IN ANTERIOR TEETH MOVEMENTS: A SYSTEMATIC REVIEW

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ABSTRACT

Introduction: Nowadays more adults want to improve their smile and some of them expect something more comfortable and more aesthetic, such as clear aligners. However, certain dental movements can be particularly difficult to control.

Objectives: To analyze the use of clear aligners for anterior teeth movements in adults, analyzing the outcome of the different types of movements using aligners (intrusion, extrusion, rotation, inclination, torque and translation or bodily movement) in the anterior sector (canine to canine), and comparing the outcome of the different types of movements in the maxilla and in the mandible.

Methods: On December 2021, an electronic search on MEDLINE and Scopus databases was performed, searching for studies published between 2001 and 2021. The quality of the evidence was assessed with the QUADAS-2 risk of bias tool.

Results: From 414 records found in databases searching, 9 relevant articles were selected (7 retrospective and 2 prospective), all of which had a low or unclear risk of overall bias. According to the literature, rounded teeth were the more difficult to rotate. About vertical movements, intrusion was defined as an inaccurate movement (44.5%), and extrusion as the least accurate tooth movement (29.6%). Two types of tipping were assessed, mesio-distal tipping (55.5%) and vestibulo-lingual/palatal tipping (56%); they were the most accurate type of movement for anterior teeth. For translation, not enough studies were included to assess accurate results. About incisive torque, it was a complex movement to perform (38.1%).

Conclusion: Despite the limitations, this systematic review suggests that clear aligners can produce all types of anterior tooth movements with a variable predictability and accuracy. No statistical difference between achieved and predicted anterior tooth movement was found when comparing the same movement applied to the same tooth but in different arches.

Key words: *Clear aligner therapy; Invisalign®; Orthodontics; Invisible orthodontics; Aesthetic appliances.*

INTRODUCTION

In recent years, an increasing number of adult patients are looking for improving their smiles. However, they desire an alternative to conventional orthodontic appliances, something more comfortable and more aesthetic, such as clear aligners. Since decades, Clear Aligner Therapy (CAT) had been a small part of orthodontic practice but in 1997, two graduate students at Stanford University applied three-dimensional (3D) computer imaging graphics to the field of orthodontics and created the world's first mass-produced, customized clear aligner system making possible the increasing popularity of the technique. They established Align technology® and release their Invisalign® system (1). There are several published systematic reviews on accuracy of aligners (2–5). In 2005, Lagravère et al. published the first systematic review about clear aligners therapy (CAT) effectiveness. They stated that no conclusion from this systematic review could be made about the indications, limitations of outcomes of use of the Invisalign system (2). More recently, several authors have updated evidence on this subject. One was published in 2014 evaluated the control of the clear aligners on orthodontic tooth movement (3). Another one realized the same year focused on the comparison between conventional braces and clear aligners (4). A most recent review undertaken in 2018 (5) stated that no clear clinical recommendations could be made.

This systematic review has been made in order to update and complete the previous reviews if changes have been demonstrated. The aim of this systematic review was to systematically review the following question: “In adults, is the use of aligners accurate when talking of anterior teeth movements?” This was done by evaluating the accuracy of movement of aligners depending on the type of movement and teeth.

MATERIAL AND METHODS

This review was planned, conducted, and reported in adherence to PRISMA standards of quality for reporting systematic reviews (6).

Focus question

The “PICO” approach was used to extract data from the selected articles:

• Population (participants): We included studies on adult (age ≥18 years-old) patients.

• Intervention: We considered patients treated with Invisalign treatment.

• Comparator: None.

• Outcomes: To be included, a study had to use a defined clinical outcome relating to efficacy of anterior teeth movement.

Information sources and data search

An automated search was carried out in two databases: MEDLINE and Scopus, using the following key words: ‘Clear aligner therapy’, ‘Invisalign®’, ‘Orthodontics’, ‘Invisible orthodontics’, ‘Aesthetic appliances’, ‘effectivity’, ‘accuracy’. To obtain more accurate studies to include in this systematic review, the two Boolean Operators, AND and OR, were used, as well as MeSH terms. On December 2021, a systematic search in MEDLINE and Scopus databases was performed, to identify all articles potentially relevant to the review’s question. Because of the differences in regulated vocabulary and syntax restrictions, detailed search algorithms were devised and suitably changed for each database. The search strategy comprised use of the following terms: “(MM "Orthodontic Appliances, Removable") AND ((accur*) OR (valid*) OR (reliab*) OR (effectiv*) OR (precis*))”.

Eligibility criteria

The inclusion criteria were:

Study design: Clinical trials referred to the accuracy of prediction of tooth movement; Published between 2001 and 2021; Any language.

Population/Teeth type: Adults patients (≥ 18 years) undergoing aligner orthodontic treatment; Superior and inferior anterior teeth (canine to canine).

Intervention: CAT; Studies with achieved final orthodontic tooth movement (intrusion, extrusion, rotation, inclination, torque and translation).

Exclusion criteria: Experimental in vitro studies; Studies without significant results.

Search strategy

The selection of the papers to include in the review has been realized in three phases by two independent reviewers (EP,AM). During the first phase, titles of all articles retrieved were screened. In the second one abstracts were filtered, to make sure they were relevant according to the criteria of the study. Subsequently, for the third phase, studies that satisfied the eligibility criteria were included through full-text assessment. In case of disagreement, consensus on which articles to include was reached by discussion. If during any phase of the process the two researchers couldn't agree, a third researcher was consulted to make the final decision (***Fig. 1***).

Extraction data

The data from the eligible research was then compiled into several tables. The first table (**Table 1**) describes the characteristics of the different studies included in this review and the following parameters: author detail, year, study design, sample characteristics, type/number of teeth, auxiliary elements, analysis methods, movement performed and outcome. The second one (**Table 2 a and b**) describes the accuracy of different types of movement for upper and lower anterior teeth. The third and last one (**Table 3**) describes the accuracy of movement for maxillary and mandibulary teeth.

Quality and risk of bias assessment

The methodological quality of the studies was determined using the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies-2) tool (7). According to the applicability of the studies, four domains were evaluated to determine the risk of bias and level of concern:

Patient selection: studies with a non-random or non-consecutive sample of patients, were deemed to have a high risk of bias.

Index test: it was rated as high risk of bias when diagnostic methods were used without knowing the results of the reference standard.

Reference standard: it was classified as high risk of bias when reference standards were conducted with knowledge of the index test results.

Flow and timing: they were assessed as having a high risk of bias when the reference standard was not applied on all patients or when all samples were not included in the study, or when a significant time had passed between the index test and the reference standard.

Concerns about the studies' applicability were assessed as follows:

Patient selection: studies with a small sample size (less than 15 patients) were defined as having a high risk of bias.

Index test: a high risk of bias was indicated when the index test implementation differed from the review question.

Reference standard: studies that didn’t use cast analysis and reliability evaluation to assess the validation of the target condition obtained a high risk of bias.

Data synthesis

In order to summarize and compare the outcome variables between the different studies, the values of the main variables were grouped according to the movement performed.

RESULTS

Study selection

414 records were found in databases searching, 230 in MEDLINE complete and 184 in Scopus. From all these studies, 38 were excluded because they didn’t fulfill the date inclusion criteria (published between 2001 and 2021). After duplicates removal, 308 titles were screened, followed by 57 abstracts and then 17 full-text documents. Finally, 9 studies met the inclusion criteria and were included in this systematic review (8–16). The article selection process is illustrated in the PRISMA Flow Diagram (***Fig. 1***).

Study characteristics

Of the 9 relevant studies identified, 7 studies were retrospective (8,11–16), and 2 studies were prospective (9,10). The sample size ranged from 16 to 69, with a total number of 295 patients, 189 women and 106 men. Invisalign® was used in all studies except for one that realized its research with F22 aligners (**Table 1**).

Risk of bias in studies

The overall risk of bias was rated as unclear in five out of nine studies (8,11,13,14,16) and as low in four studies (9,10,12,15) (**Figure 2 a and b**).

Results of individual studies

Types of movement

- Intrusion: Kravitz et al. (10) found the highest accuracy of intrusion for the maxillary (44.7%) and mandibular (46.6%) central incisors. The lowest accuracy of intrusion was attributed to the maxillary lateral incisors (32.5%). Charalampakis et al. (14) defined the intrusion of incisors as the most inaccurate of all linear movements, with a difference ranging from 1.1mm to 1.5mm. Al-balaa et al. (8) agreed with this statement.

- Extrusion: Extrusion of the upper (18.3%) and lower (24.5%) central incisors was defined as the least accurate tooth movement (10). In Charalampakis' study (14), the achieved extrusion was often larger than predicted, even though the difference was not statistically significant.

- Rotation: Several authors (9,10,13,14) demonstrated that rotation of canines using clear aligners was more complex to achieved compared to incisors.

- Translation: Both Charalampakis et al. (14) and Jiang et al. (15) found that horizontal movements of all incisors seemed to be accurate, with small (0.20-0.25mm) or insignificant differences between predicted and achieved amounts (14).

- Torque: Simon et al. (11) found a mean accuracy of 42% for torque of upper central incisors. Jiang et al. (15) defined torque as the lowest accuracy achieved (35.2%). In 2021 Gaddam et al. (16) evaluated the accuracy depending on the direction to move showing that incisor torque is under-expressed when incisors are programmed to move labially and over-expressed to a minor extent when programmed to move lingually. Grünheid et al. (12) found that all lower anterior teeth and the upper canines the final crown torque was more buccal than predicted. In contrast, for upper central and lateral the final crown torque was more lingual.

- Mesiodistal tipping: Kravitz et al. (10) assessed that the tipping of the canines was the least accurate. In the F22 aligners study (13), the most accurate movement achieved was mesiodistal tipping (82.1%), with the most precise movements achieved by lower incisors (87.7%) and lower canines (86.7%). Grünheid et al. (12) affirmed that all anterior teeth had a more distal position than predicted, ranging from +0.51mm to +0.31mm, except the mandibular central incisor that was more mesial (-0.36mm).

- Vestibulolingual tipping: Kravitz et al. (10) found a similar accuracy for all anterior teeth, ranging between 40.3% to 47.6%. In another study (13), the least accurate movement was vestibulolingual tipping of upper canines (54.0%). Jiang et al. (15) evaluated the accuracy of vestibulolingual tipping of incisors and demonstrated that pure tipping (72.5%) was more predictable than controlled tipping (65.2%).

All the results are presented in **Table 2 a and b**.

Maxilla VS mandible

- Intrusion and extrusion: Kravitz et al. (10) found similar results in both maxilla and mandible for all anterior teeth.
- Rotation: All three studies (9,10,13) found no statistically significant difference.
- Translation: A significant difference was found in efficacy between the maxillary and mandibular incisors in Jiang's study (15). Translation of the maxillary incisors showed statistically less efficacy (43.2% and 39.9%) than that of the mandibular ones (58.0% and 54.7%).
- Torque: No significant difference was found (15).
- Mesiodistal tipping: No significant difference was found (10,13).
- Vestibulolingual tipping: No significant difference was found in 3 studies (9,10,15).

In the study of Lombardo et al. (13), the accuracy of movement of for both maxillary and mandibular incisives was different with a lower efficiency of tipping for the upper ones (64.5%) compared to the lower ones (86.1%).

All the results are presented in **Table 3**.

DISCUSSION

This systematic literature study has identified evidence of the differences in accuracies depending on the type of movement performed on different teeth with CAT.

Types of movement

- Intrusion: The three studies (8,10,14) included in this review defined intrusion as an inaccurate movement. Another review (3) affirmed that CAT could be recommended for the treatment of simple malocclusions with light overbite discrepancies but not complex ones. Based on this literature it has been demonstrated that anterior tooth Intrusion is a challenging movement to produce with CAT.

- Extrusion: It seems one of the most critical movements to be carried out with CAT. However, when comparing the results of the two authors included in this literature, a difference can be noticed. In Charalampakis et al. study (14) extrusion of incisors appeared to be accurate, since no statistically significant differences were observed. On the other side, Kravitz (10) found that only 13 of the 64 teeth had attempted extrusions greater than 1.0 mm, and no tooth had an attempted extrusion greater than 2 mm. Several authors in literature have highlighted this critical issue. In a previous review made in 2015 (3), it was demonstrated that CAT is not effective in controlling anterior extrusion movement of anterior teeth resulting in the fact that open bite is a challenging malocclusion to treat. This difficulty in performing extrusive movement can be explained by the poor capacity of the aligner to grasp the tooth during vertical pull.

- Rotation: All studies (9,10,13,14) found the same conclusion, rounded teeth, mandibular and maxillary canines, are more difficult to rotate compared to incisors. Kravitz et al. (10) found that the accuracy of rotation of canine was smaller compared to incisors and that the predictability of canine rotation was significantly decreased for movements greater than 15°. As well, Lombardo et al. (13) defined the rotation of canines as the least efficient movement in his study. Charalampakis et al. (14) assessed that the difference between the predicted and the actual outcome of the maxillary canines was the greatest one, followed by the mandibular canines. These results are in line with a review realized in 2021 (17) that concluded that the prediction of rotational tooth movements with aligner treatment does not appear accurate, especially for canines. All these findings suggest that tooth rotation rounded teeth with aligners are challenging movements and it could be explained by the fact that cylindric teeth struggled to grip the aligners.

- Translation: Charalampakis at al. (14) found that translation of incisors was accurate with small or insignificant differences between predicted and achieved amounts. Furthermore, Jiang et al. (15) expressed a difference between maxillary and mandibular incisors. No other reviews describing this movement were found.

- Torque: In this review, the mean accuracy found was small, indicating that it is a complex movement to realize. Indeed, Simon et al. (11) concluded that upper incisor torque is a challenging movement to perform with clear aligners, and that it is essential to consider that overcorrections or case refinements may be needed, since the ClinCheck® simulation could predict more movement than what may result clinically. As well, Grünheid et al. (12) assessed high discrepancies for the torque of upper central incisor and lower canines. Similar results were found in Jiang et al. study (15). Torque was defined as the lowest accuracy achieved. In his study, Gaddam et al. (16) evaluated the accuracy depending on the direction to move. He expressed that incisor torque is under-expressed when incisors are programmed to move labially and over-expressed to a minor extent when incisors are programmed to move lingually, and that lower incisors demonstrated a more reliable expression of torque than the upper incisors. These results suggest that the least accurate torque movements appear on the maxillary central incisor.

- Tipping: It is one of the most predictable movement with CAT. All the authors assessed that the mean accuracy of tipping of canines was slightly lower than incisors one (10,12,13). All these results were in line with a review made in 2015 (3) where it was demonstrated a scarce result in tipping canines. This suggest that teeth with larger roots might have greater difficulty achieving mesiodistal movements. These teeth have the longest roots in the dentition with large root surface areas, requiring greater force to produce orthodontic tooth movement (12).

Maxilla VS mandible

The findings about the accuracy of movement comparing maxillary and mandibulary teeth need to be interpreted with caution because of the small number of studies. These findings indicated that no statistical significance difference was found for all types of movements when comparing the same movement for the same teeth in each arch. However, only a study (15) assessed a significance difference between the accuracy of translation of upper incisors and lower ones. The maxillary central and lateral incisors showed statistically less efficacy than the mandibular central and lateral incisors. As well, in the study of Lombardo et al. (13), the accuracy of vestibulolingual tipping for both maxillary and mandibular incisives was different with a lower efficiency of tipping for the upper ones compared to the lower ones.

Limitations of the study

The limitations of this study should be discussed in order to interpret the results correctly. First, as with all systematic reviews, we examined electronic databases and conducted a manual search, which may have limited the number of publications found and included in the review. Second, the sample size of the included studies was generally small with the lack of proper blinding procedures and the absence of sample randomization procedures. Third, in this review, the use of auxiliaries such as IPR, Power Ridge, or attachments was not considered when comparing the results. In most of the studies, the supervising orthodontist was presumed to have had sufficient experience to prescribe them appropriately, and no restrictions were applied. Clearly, successful clear aligner treatment is not limited to aligners alone. Fourth, the posterior teeth were not considered in this review. However, the movement of one anterior is not independent from the movement of adjacent or posterior teeth. As well, much more parameters can influence tooth movement, so it would be useful to explore and include the influence of other factors, such as the patient's age, sex, periodontal support, bone density or systemic factors, in future research.

CONCLUSION

- Clear aligners can produce all types of anterior tooth movements with a variable predictability and accuracy. Vertical anterior movements are inaccurate, especially when talking of anterior extrusion movement. CAT is also not effective in controlling rotations of rounded teeth (canines). Not enough studies are made about translation in order to conclude an accurate result. About torque, it is a challenging movement to achieve with CAT, particularly for maxillary central incisor. Finally, tipping of anterior teeth is the most predictable movement to perform with CAT, but it appears more difficult for canines because of their larger root surface areas.

- No statistical difference between achieved and predicted anterior tooth movement was found when comparing the same movement applied to the same tooth but in different arches.

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APPENDIX:

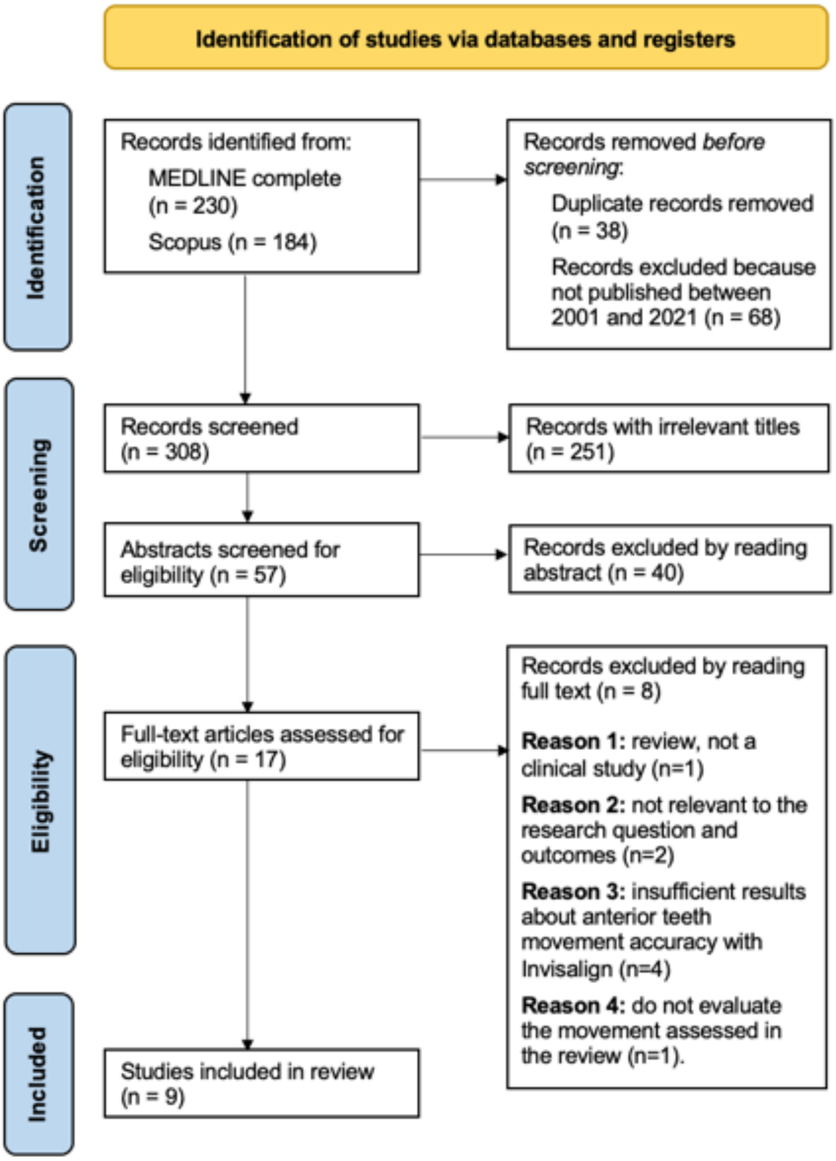

Fig. 1: *PRISMA flowchart of searching and selection process of titles during systematic review*

Fig. 2a. *Risk of bias assessment and applicability concerns (QUADAS-2).*

Study	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Kravitz et al. 2008 (24)	☺	☺	☺	☺	☺	☺	☺
Kravitz et al. 2009 (25)	☺	☺	☺	☺	☺	☺	☺
Simon et al. 2014 (26)	☺	?	?	☺	☺	☺	☺
Grünheid et al. 2017 (27)	☺	☺	☺	☺	☺	☺	☺
Lombardo et al. 2017 (28)	?	?	?	☺	☺	☺	☺
Charalampakis et al. 2018 (10)	?	?	?	☺	☺	☺	☺
Jiang et al. 2021 (29)	☺	☺	☺	☺	☺	☺	☺
Al-balaa et al. 2021 (11)	?	?	?	☺	☺	☺	☺
Gaddam et al. 2021 (30)	?	☺	?	☺	☺	☺	☺

☺ Low ☹ High ? Unclear

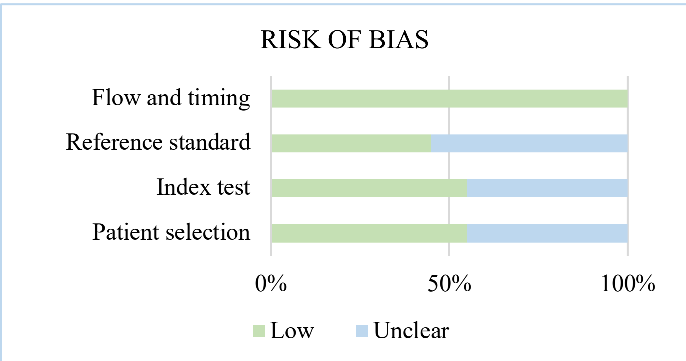

Fig. 2b: *Risk of bias assessment of included studies according to QUADAS-2 tool.*

Table 1: *General characteristics of the included studies.*

Study	Sample characteristics	Teeth	Auxiliary Elements	Analysis Methods	Movements	Outcomes
Kravitz et al. 2008 (9) Prospective study	31 pts (18 F, 13 M) Mean age: 29.4 y	53 C	Att only IPR only N	Superimposition of the final stage of the pre-treatment model (ClinCheck®) and the post-treatment model	Rotation	Comparison between the predicted amount of rotation and the actual amount of rotation achieved
Kravitz et al. 2009 (10) Prospective study	37 pts (23 F,14 M) Mean age: 31 y	401 anterior teeth	IPR or Att or N	Superimposition of the virtual model of the predicted tooth position and the virtual model of the achieved tooth position	Intrusion Extrusion MD tip VL tip Rotation	Comparison between the predicted amount of movement (intrusion, extrusion, mesiodistal tip, labiolingual tip, and rotation) and the actual amount of movement achieved
Simon et al. 2014 (11) Retrospective study	30 pts (19 F, 11 M) Mean age: 32.9 y	14 CI	Att Power Ridge	Superimposition of the initial situation and the final stage of ClinCheck® Superimposition of the initial situation and the actual post-treatment condition	Torque	Investigation of the treatment efficacy for Torque movement in predefined tooth.
Grünheid et al. 2017 (12) Retrospective study	30 pts (17 F, 13 M) Mean age: 21.6 ± 9.8 y	Anterior teeth	IPR or Att or N	Superimposition of individual teeth from segmented posttreatment model and the corresponding teeth in unsegmented virtual treatment model with e-model Compare 8.1 software (GeoDigm).	Rotation Tipping Torque Translation	Quantification of the differences between achieved and predicted position for each tooth in the following six directions: mesial-distal, facial-lingual, occlusal-gingival, tip, torque, and rotation.
Lombardo et al. 2017 (13) Retrospective study	16 pts (10 F, 6 M) Mean age: 28 y 7 mo	180 anterior teeth	IPR or Att or N	Analyze of pre-treatment, ideal post-treatment and real post-treatment digital models with VAM software	Rotation MD tip VL tip	Comparison between the predicted amount of movement (rotation, MD tipping, VL tipping) and the actual amount of movement achieved
Charalampakis et al. 2018 (14) Retrospective study	20 pts (17 F, 3 M) Mean age: 37 y 6 mo	Anterior teeth	IPR or Att or N	Superimposition of predicted and achieved models and initial models with 3-dimensional Image Analysis open-source software Slicer CMF.	Rotation Intrusion Extrusion Translation	Comparison between the predicted amount of tooth movement and the achieved amount for each movement (rotation, intrusion, extrusion, translation)
Jiang et al. 2021 (15) Retrospective study	69 pts (44 F, 25 M) Mean age: 28.5 ± 5.7 y	231 I	-	Superimposition of the virtual incisor position, the posttreatment incisor position and the pretreatment position with Mimics software	Pure tipping Controlled tipping Translation Torque	Comparison between the predicted and achieved incisor movement

Al-balaa et al. 2021 (8) Retrospective study	22 pts (12 F, 10 M) Mean age: 23.74 y	142 anterior teeth	Att	Superimposition of the pretreatment and posttreatment CBCT scans	Intrusion	Comparison of the predicted and actual quantities of each tooth intrusion movement
Gaddam et al. 2021 (16) Retrospective study	40 pts (29 F, 11 M) Mean age: 25.5 y	I	No IPR	Superimposition T0 (pretreatment) and T1 models (predicted post-treatment) Superimposition of T0 and R stage models (end of initial aligner sequence)	Torque	Comparison between the predicted and the achieved torque movement

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; F, Female; M, Male; IPR, Interproximal reduction; N, Neither attachment nor interproximal reduction; MD, mesiodistal; VL, vestibulolingual.

Tab. 2a: *Accuracy of different types of movement for upper and lower anterior teeth.*

Author, year	Teeth	N° of teeth	Intrusion (n° of teeth)	Extrusion (n° of teeth)	Rotation (n° of teeth)	MD tip (n° of teeth)
Maxillary teeth						
Kravitz et al. 2008 (9)	C	20	-	- - -	21.0% (2) 45.9% (9) 27.5% (9)	- - -
Kravitz et al. 2009 (10)	CI LI C	203	46.6% (37) 40.0% (42) 39.5% (32)	24.5% (11) 28.4% (4) 30.4% (3)	48.8% (64) 51.6% (57) 29.1% (55)	39.6% (37) 48.6% (41) 26.9% (20)
Grünheid et al. 2017 (12)	CI LI C	-	-	-	-0.60° -0.99° +0.88°	-0.36mm +0.51mm +0.39mm
Lombardo et al. 2017 (13)	I C	94	- -	- -	67.0% (51) 54.2% (25)	87.7% (31) 86.7% (18)
Charalampakis et al. 2018 (14)	I C	-	0.80mm (64) 0.30mm (40)	-0.30mm (16) 0.30mm (40)	1.85° (80) 2.45° (40)	- -
Al-balaa et al. 2021 (8)	I C	92	44.7% (74) 52.3% (18)	- -	- -	- -
Mandibulary teeth						
Kravitz et al. 2008 (9)	C	53	-	-	35.8% (53)	-
Kravitz et al. 2009 (10)	CI, LI, C	401	41.3% (189)	29.6% (64)	43.2% (344)	40.5% (180)
Lombardo et al. 2017 (13)	I, C	180	- -	- -	62.4% (146)	82.1% (101)
Charalampakis et al. 2018 (14)	CI, LI, C	-	0.62mm (184)	-0.06mm (136)	2.18° (240)	-
Al-balaa et al. 2021 (8)	CI, LI, C	142	48.8% (142)	- - -	- - -	- - -

I, Incisive; CI, Central Incisive; C, Canine.

***Tab. 2b:** Accuracy of different types of movement for upper and lower anterior teeth.*

Author, year	Teeth	N° of teeth	VL tip (n° of teeth)	Torque (n° of teeth)	Translation (n° of teeth)
			Maxillary teeth		
Kravitz et al. 2009 (9)	CI LI C	203	44.2% (39) 47.4% (49) 43.7% (34)	- - -	- - -
Grünheid et al. 2017 (12)	CI LI C	-	-	-0.66° -0.29° -1.60°	-
Lombardo et al. 2017 (13)	I C	94	86.1% (35) 66.4% (15)	- -	- -
Charalampakis et al. 2018 (14)	I C	-	- -	- -	0.00mm (80) 0.20mm (40)
Jiang et al. 2021 (15)	CI LI	116	PT CT 77.2% (15) 66.7% (13) 77.4% (14) 66.8% (17)	40.6% (15) 37.2% (13)	58.0% (14) 54.7% (15)
Gaddam et al. 2021 (16)	I	160	-	L P 2.75° (112) -0.67° (48)	-
			Mandibulary teeth		
Kravitz et al. 2009 (9)	CI, LI, C	401	44.7% (257)	-	-
Simon et al. 2014 (11)	CI (mx)	14	- -	50.3% (14)	-
Lombardo et al. 2017 (13)	I, C	180	71,1% (94)	-	-
Charalampakis et al. 2018 (14)	CI, LI, C	-	-	-	0.14mm (240)
Jiang et al. 2021 (15)	CI, LI	231	PT CT 72.5% (56) 65.2% (61)	35.2% (59)	49.5% (55)
Gaddam et al. 2021 (16)	I	320	-	L P 4.23° (219) -0.39° (101)	-

I, Incisive; CI, Central Incisive; C, Canine.

***Tab. 3:** Accuracy of movement for maxillary and mandibulary teeth.*

Author, year	Movement	Teeth	Max (n° of teeth)	Mdb (n° of teeth)
Kravitz et al. 2008 (9)	Rotation	C	36.2% (33)	35.0% (20)
Kravitz et al. 2009 (10)	Intrusion	CI LI C	44.7% (39) 32.5% (22) 40.0% (17)	46.6% (37) 40.0% (42) 39.5% (32)
	Extrusion	CI LI C	18.3% (12) 28.4% (23) 49.9% (11)	24.5% (11) 28.4% (4) 30.4% (3)
	Rotation	C	32.2% (57)	29.1% (55)
	MD tipping	CI LI C	38.6% (26) 43.1% (39) 35.5% (17)	39.6% (37) 48.6% (41) 26.9% (20)
	VL tipping	CI LI C	40.3% (51) 47.6% (53) 44.6% (31)	44.2% (39) 47.4% (49) 43.7% (34)
Lombardo et al. 2017 (13)	Rotation	I C	61.5% (45) 62.3% (25)	67% (51) 54.2% (25)
	MD tipping	I C	76.7% (36) 78.3% (16)	87.7% (31) 86.7% (18)
	VL tipping	I C	64.5% (28) 54.0% (16)	86.1% (35) 66.4% (15)
Jiang et al. 2021 (15)	VL PT	CI LI	65.4% (13) 69.1% (14)	77.2% (15) 77.4% (14)
	VL CT	CI LI	64.8% (16) 62.7% (15)	66.7% (13) 66.8% (17)
	Torque	CI LI	31.8% (13) 31.7% (18)	40.6% (15) 37.2% (13)
	Translation	CI LI	43.2% (16) 39.9% (10)	58.0% (14) 54.7% (15)

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; MD, mesiodistal; VL, vestibulolingual.

APPENDIX 3. Tables

Table 4. *General characteristics of the included studies.*

Author, year	Study design	Sample characteristics	Teeth	Auxiliary Elements	Analysis Methods	Movements	Outcomes
Kravitz et al. 2008 (24)	Prospective study	31 pts (18 F, 13 M) Mean age: 29.4 y	53 C	Att only IPR only N	Superimposition of the final stage of the pre-treatment model (ClinCheck®) and the post-treatment model	Rotation	Comparison between the predicted amount of rotation and the actual amount of rotation achieved
Kravitz et al. 2009 (25)	Prospective study	37 pts (23 F,14 M) Mean age: 31 y	401 anterior teeth	IPR or Att or N*	Superimposition of the virtual model of the predicted tooth position and the virtual model of the achieved tooth position	Intrusion Extrusion MD tip VL tip Rotation	Comparison between the predicted amount of movement (intrusion, extrusion, mesiodistal tip, labiolingual tip, and rotation) and the actual amount of movement achieved
Simon et al. 2014 (26)	Retrospective study	30 pts (19 F, 11 M) Mean age: 32.9 y	14 CI	Att Power Ridge	Superimposition of the initial situation and the final stage of ClinCheck® Superimposition of the initial situation and the actual post-treatment condition	Torque	Investigation of the treatment efficacy for Torque movement in predefined tooth.
Grünheid et al. 2017 (27)	Retrospective study	30 pts (17 F, 13 M) Mean age: 21.6 ± 9.8 y	Anterior teeth	IPR or Att or N*	Superimposition of individual teeth from segmented posttreatment model and the corresponding teeth in unsegmented virtual treatment model with e- model Compare 8.1 software (GeoDigm).	Rotation Tipping Torque Translation	Quantification of the differences between achieved and predicted position for each tooth in the following six directions: mesial-distal, facial-lingual, occlusal-gingival, tip, torque, and rotation.
Lombardo et al. 2017 (28)	Retrospective study	16 pts (10 F, 6 M) Mean age: 28 y 7 mo	180 anterior teeth	IPR or Att or N*	Analyze of pre-treatment, ideal post-treatment and real post-treatment digital models with VAM software	Rotation MD tip VL tip	Comparison between the predicted amount of movement (rotation, MD tipping, VL tipping) and the actual amount of movement achieved

Table 4. *Cont.*

Author, year	Study design	Sample characteristics	Teeth	Auxiliary Elements	Analysis Methods	Movements	Outcomes
Charalampakis et al. 2018 (10)	Retrospective study	20 pts (17 F, 3 M); Mean age: 37 y 6 mo	Anterior teeth	IPR or Att or N*	Superimposition of predicted and achieved models and initial models with 3-dimensional Image Analysis open-source software Slicer CMF.	Rotation Intrusion Extrusion Translation	Comparison between the predicted amount of tooth movement and the achieved amount for each movement (rotation, intrusion, extrusion, translation)
Jiang et al. 2021 (29)	Retrospective study	69 pts (44 F, 25 M) Mean age: 28.5 ± 5.7 y	231 I	-	Superimposition of the virtual incisor position, the posttreatment incisor position and the pretreatment position with Mimics software	Pure tipping Controlled tipping Translation Torque	Comparison between the predicted and achieved incisor movement
Al-balaa et al. 2021 (11)	Retrospective study	22 pts (12 F, 10 M) Mean age: 23.74 y	142 anterior teeth	Att	Superimposition of the pretreatment and posttreatment CBCT scans	Intrusion	Comparison of the predicted and actual quantities of each tooth intrusion movement
Gaddam et al. 2021 (30)	Retrospective study	40 pts (29 F, 11 M) Mean age: 25.5 y	I	No IPR	Superimposition the T0 model (pretreatment) and the T1 models (predicted post-treatment) Superimposition of the pretreatment (T0) model and the R stage models (end of initial aligner sequence)	Torque	Comparison between the predicted and the achieved torque movement

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; F, Female; M, Male; IPR, Interproximal reduction; N, Neither attachment nor interproximal reduction; MD, mesiodistal; VL, vestibulolingual.
**In these studies clinicians were allowed to request or refuse IPR and attachments at their discretion but no precision is made when presenting the results.*

Table 5. *Accuracy of different types of movement for maxillary incisors and canines.*

Author, year	Study design	Sample size	Mean age	Teeth	N° of teeth	Auxiliary	Intrusion (n° of teeth)	Extrusion (n° of teeth)	Rotation (n° of teeth)	MD tip (n° of teeth)	VL tip (n° of teeth)	Torque (n° of teeth)	Translation (n° of teeth)
Kravitz et al. 2008 (24)	Prospective study	31 pts	29.4 y	C	33	Att only IPR only N	-	- - -	34.9% (15) 40.3% (9) 34.2% (9)	- - -	- - -	- - -	- - -
Kravitz et al. 2009 (25)	Prospective study	37 pts	31 y	CI LI C	198	IPR or Att or N*	44.7% (39) 32.5% (22) 40.0% (17)	18.3% (12) 28.4% (23) 49.9% (11)	54.2% (52) 43.4% (59) 32.2% (57)	38.6% (26) 43.1% (39) 35.5% (17)	40.3% (51) 47.6% (53) 44.6% (31)	- - -	- - -
Simon et al. 2014 (26)	Retrospective study	30 pts	32.9 y	CI	14	Att PR	- -	- -	- -	- -	- -	49.1% (7) 51.5% (7)	- -
Grünheid et al. 2017 (27) †	Retrospective study	30 pts	21.6 ± 9.8 y	CI LI C	-	IPR or Att or N*	-	-	-0.33° -0.70° +0.19°	+0.42mm +0.35mm +0.31mm	-	+1.75° +0.08° -0.48°	-
Lombardo et al. 2017 (28)	Retrospective study	16 pts	28 y 7 mo	I C	86	IPR or Att or N*	- -	- -	61.5% (45) 62.3% (25)	76.7% (36) 78.3% (16)	64.5% (28) 54.0% (16)	- -	- -
Charalampakis et al. 2018 (10) ‡	Retrospective study	20 pts	37 y 6 mo	CI LI C	-	IPR or Att or N*	1.50mm (22) 1.10mm (18) -0.10mm (40)	-0.30mm (18) -0.25mm (22) -0.10mm (40)	2° (40) 1.85° (40) 3.05° (40)	- - -	- - -	- - -	0.25mm (40) 0.25mm (40) 0.20mm (40)
Jiang et al. 2021 (29)	Retrospective study	69 pts	28.5 ± 5.7 y	CI LI	115	-	- -	- -	- -	- -	PT: 65.4% (13), 69.1% (14) CT: 64.8% (16), 62.7% (15)	31.8% (13) 31.7% (18)	43.2% (16) 39.9% (10)
Al-balaa et al. 2021 (11)	Retrospective study	22 pts	23.74 y	CI LI C	50	Att	51.8% (22) 58.1% (19) 49.0% (9)	- - -	- - -	- - -	- - -	- - -	- - -
Gaddam et al. 2021 (30) ‡	Retrospective study	40 pts	25.5 y	CI LI	160	-	- -	- -	- -	- -	- -	L: 6.43° (56), 5.06° (51) P: -0.73° (24), 0.36° (29)	- -

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; IPR, Interproximal reduction; N, Neither attachment nor interproximal reduction; MD, mesiodistal; VL, vestibulolingual; L, lingual; P, palatal; PT, pure tipping; CT, controlled tipping.

**In these studies clinicians were allowed to request or refuse IPR and attachments at their discretion but no precision is made when presenting the results.*

†In this study, positive values indicate an achieved tooth position with more distal crown tip, more lingual crown torque, or more distal rotation than the predicted tooth position.

‡In these studies, a negative sign indicates that the achieved value was greater than the predicted one.

***Table 6**. Accuracy of different types of movement for mandibular incisors and canines.*

Author, year	Study design	Sample size	Mean age	Teeth	N° of teeth	Auxiliary	Intrusion (n° of teeth)	Extrusion (n° of teeth)	Rotation (n° of teeth)	MD tip (n° of teeth)	VL tip (n° of teeth)	Torque (n° of teeth)	Translation (n° of teeth)
Kravitz et al. 2008 (24)	Prospective study	31 pts	29.4 y	C	20	Att only IPR only N	-	- - -	21.0% (2) 45.9% (9) 27.5% (9)	- - -	- - -	- - -	- - -
Kravitz et al. 2009 (25)	Prospective study	37 pts	31 y	CI LI C	203	IPR or Att or N*	46.6% (37) 40.0% (42) 39.5% (32)	24.5% (11) 28.4% (4) 30.4% (3)	48.8% (64) 51.6% (57) 29.1% (55)	39.6% (37) 48.6% (41) 26.9% (20)	44.2% (39) 47.4% (49) 43.7% (34)	- - -	- - -
Grünheid et al. 2017 (27) †	Retrospective study	30 pts	21.6 ± 9.8 y	CI LI C	-	IPR or Att or N*	-	-	-0.60° -0.99° +0.88°	-0.36mm +0.51mm +0.39mm	-	-0.66° -0.29° -1.60°	-
Lombardo et al. 2017 (28)	Retrospective study	16 pts	28 y 7 mo	I C	94	IPR or Att or N*	- -	- -	67.0% (51) 54.2% (25)	87.7% (31) 86.7% (18)	86.1% (35) 66.4% (15)	- -	- -
Charalampakis et al. 2018 (10) ‡	Retrospective study	20 pts	37 y 6 mo	I C	-	IPR or Att or N*	0.80mm (64) 0.30mm (40)	-0.30mm (16) 0.30mm (40)	1.85° (80) 2.45° (40)	- -	- -	- -	0.00mm (80) 0.20mm (40)
Jiang et al. 2021 (29)	Retrospective study	69 pts	28.5 ± 5.7 y	CI LI	116	-	- -	- -	- -	- -	PT 77.2% (15), CT 66.7% (13) PT 77.4% (14), CT 66.8% (17)	40.6% (15) 37.2% (13)	58.0% (14) 54.7% (15)
Al-balaa et al. 2021 (11)	Retrospective study	22 pts	23.74 y	I C	92	Att	44.7% (74) 52.3% (18)	- - -	- - -	- - -	- - -	- - -	- - -
Gaddam et al. 2021 (30) ‡	Retrospective study	40 pts	25.5 y	I	160	-	- -	- -	- -	- -	- -	L 2.75° (112) P -0.67° (48)	- -

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; IPR, Interproximal reduction; N, Neither attachment nor interproximal reduction; MD, mesiodistal; VL, vestibulolingual; L, lingual; P, palatal; PT, pure tipping; CT, controlled tipping.
**In these studies clinicians were allowed to request or refuse IPR and attachments at their discretion but no precision is made when presenting the results.*
†In this study, positive values indicate an achieved tooth position with more distal crown tip, more lingual crown torque, or more distal rotation than the predicted tooth position.
‡In these studies, a negative sign indicates that the achieved value was greater than the predicted one.

Table 7. *Weighted average of each type of movement.*

Author, year	Study design	Sample size	Mean age	Teeth	N° of teeth	Auxiliary	Intrusion (n° of teeth)	Extrusion (n° of teeth)	Rotation (n° of teeth)	MD tip (n° of teeth)	VL tip (n° of teeth)	Torque (n° of teeth)	Translation (n° of teeth)
Kravitz et al. 2008 (24)	Prospective study	31 pts	29.4 y	C	53	Att only or IPR only or N	-	- - -	35.8% (53)	- - -	- - -	- - -	- - -
Kravitz et al. 2009 (25)	Prospective study	37 pts	31 y	CI, LI, C	401	IPR or Att or N*	41.3% (189)	29.6% (64)	43.2% (344)	40.5% (180)	44.7% (257)	-	-
Simon et al. 2014 (26)	Retrospective study	30 pts	32.9 y	CI (mx)	14	Att or PR	- -	- -	- -	- -	- -	50.3% (14)	- -
Lombardo et al. 2017 (28)	Retrospective study	16 pts	28 y 7 mo	I, C	180	IPR or Att or N*	- -	- -	62.4% (146)	82.1% (101)	71,1% (94)	-	-
Charalampakis et al. 2018 (10) ‡	Retrospective study	20 pts	37 y 6 mo	CI, LI, C	-	IPR or Att or N*	0.62mm (184)	-0.06mm (136)	2.18° (240)	- -	- -	-	0.14mm (240)
Jiang et al. 2021 (29)	Retrospective study	69 pts	28.5 ± 5.7 y	CI, LI	231	-	-	-	-	-	PT 72.5% (56) CT 65.2% (61)	35.2% (59)	49.5% (55)
Al-balaa et al. 2021 (11)	Retrospective study	22 pts	23.74 y	CI, LI, C	142	Att	48.8% (142)	- - -	- - -	- - -	- - -	- - -	- - -
Gaddam et al. 2021 (30) ‡	Retrospective study	40 pts	25.5 y	I	320	-	-	-	-	-	-	L 4.23° (219) P -0.39° (101)	-

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; F; IPR, Interproximal reduction; N, Neither attachment nor interproximal reduction; MD, mesiodistal; VL, vestibulolingual; L, lingual; P, palatal;, PT, pure tipping; CT, controlled tipping.
**In these studies clinicians were allowed to request or refuse IPR and attachments at their discretion but no precision is made when presenting the results.*
‡*In these studies, a negative sign indicates that the achieved value was greater than the predicted one.*

Table 9. *Accuracy of movement for maxillary and mandibulary teeth.*

Author, year	Study design	Sample size	Mean age	Movement	Teeth	Max (n° of teeth)	Mdb (n° of teeth)
Kravitz et al. 2008 (24)	Prospective study	31 pts	29.4 y	Rotation	C	36.2% (33)	35.0% (20)
Kravitz et al. 2009 (25)	Prospective study	37 pts	31 y	Intrusion	CI	44.7% (39)	46.6% (37)
					LI	32.5% (22)	40.0% (42)
					C	40.0% (17)	39.5% (32)
				Extrusion	CI	18.3% (12)	24.5% (11)
					LI	28.4% (23)	28.4% (4)
					C	49.9% (11)	30.4% (3)
				Rotation	C	32.2% (57)	29.1% (55)
				MD tipping	CI	38.6% (26)	39.6% (37)
					LI	43.1% (39)	48.6% (41)
					C	35.5% (17)	26.9% (20)
				VL tipping	CI	40.3% (51)	44.2% (39)
					LI	47.6% (53)	47.4% (49)
					C	44.6% (31)	43.7% (34)
Lombardo et al. 2017 (28)	Retrospective study	16 pts	28 y 7 mo	Rotation	I	61.5% (45)	67% (51)
					C	62.3% (25)	54.2% (25)
				MD tipping	I	76.7% (36)	87.7% (31)
					C	78.3% (16)	86.7% (18)
				VL tipping	I	64.5% (28)	86.1% (35)
					C	54.0% (16)	66.4% (15)
Jiang et al. 2021 (29)	Retrospective study	69 pts	28.5 ± 5.7 y	VL PT	CI	65.4% (13)	77.2% (15)
					LI	69.1% (14)	77.4% (14)
				VL CT	CI	64.8% (16)	66.7% (13)
					LI	62.7% (15)	66.8% (17)
				Torque	CI	31.8% (13)	40.6% (15)
					LI	31.7% (18)	37.2% (13)
				Translation	CI	43.2% (16)	58.0% (14)
					LI	39.9% (10)	54.7% (15)

I, Incisive; CI, Central Incisive; C, Canine; pts, patients; MD, mesiodistal; VL, vestibulolingual; mx, maxilla; mdb, mandible.