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EFFECTIVENESS OF INVISALIGN® IN UPPER INCISORS' MOVEMENTS: A SYSTEMATIC REVIEW

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Abstract

Objectives: *The aim of this systematic review is to review all the evidence available about the efficacy of the Invisalign® system in upper incisors' movements in the last decade, since 2010.* ***Materials and Methods****: A search strategy was performed in a number of databases to include as many studies as possible. MEDLINE, Scopus, Pubmed and the Cochrane Oral Health databases were searched. 10 studies were included in the systematic review.* ***Results****: Incisor rotation and extrusion seemed to be the most predictable movements (all results had a predictability score of more than 50%), whilst torque and translation seemed to be the most difficult to be performed (most results were under 50%). Intrusion movements seemed also to be overcorrected (142.4%), resulting in possible apex resorption if not calibrated correctly.* ***Conclusions****: Single isolated dental movements seem to be predictable with the Invisalign® system, but major complex movements seem to be more unpredictable. The most predictable types of movements seem to be incisor rotation and extrusion, whilst the least predictable seem to be incisor torque and translation. Further studies are needed to examine further the predictability of the Invisalign® system considering more variables influencing the results of the studies.*

Keywords*: Invisalign, upper incisor, efficacy, effectiveness*

Introduction

In the last two decades, the use of clear aligners, especially of the Invisalign® system has exponentially increased and has increasingly replaced the use of fixed appliances, due to its better esthetics and better efficacy throughout the years.[1] Special importance has been given to the upper incisors, whose correct orientation is decisive for correct and pleasing esthetics. All the systematic reviews recently done about the efficacy of clear aligners[1-3], were either comparing the efficacy of aligners with fixed appliances or evaluating the efficacy of clear aligners in all the teeth. The authors felt that these types of systematic reviews were too general and definite conclusions could not be drawn as too many teeth and types of movements were included in a systematic review. In addition, reviewing different clear aligner systems was, in the authors' opinion, a hindrance for evaluating the real efficacy of each particular system, so the decision was taken to evaluate the efficacy of only one system, the most popular.

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For these reasons, the aim of this systematic review was to review all the evidence available about the efficacy of the Invisalign® system in upper incisors' movements in the last decade. The time frame of ten years was used as the Invisalign® system is in continuous evolution, Power Ridges® and different attachment types have been introduced throughout the years and potentially changed the efficacy of the system in performing certain types of movements. The decision to review only upper incisor movements was because these teeth have a high esthetic importance and have very similar characteristics, so that, hopefully, at the end of this systematic review, definite conclusions can be drawn and, subsequently, clinicians can execute treatments in the esthetic zone with the Invisalign® system with more confidence.

Materials and methods

Types of studies

Any type of study (randomized clinical trials (RCTs) or prospective and retrospective studies) was considered to be included in this review, whose attempt was to include as much evidence as possible. For the same reason, no restrictions in languages of the publications or publication status was applied. The only restriction applied was that the articles had to be from the last decade (research from 2010 to present), as the Invisalign® system has evolved and changed a lot from its introduction in 1997.[1]

Types of participants

No restriction in the age of participants was applied as long as they were treated with Invisalign®.

Types of interventions

Studies in which patients were treated with Invisalign®, to correct the position of maxillary incisors, were exclusively examined. All the other studies examining other types of aligner systems were excluded.

Outcomes examined

Any study examining the efficacy of the Invisalign® system in performing any type of movement in maxillary incisors was included. In most studies, the efficacy was measured as a percentage by comparing the predicted movement by the ClinCheck® system of Invisalign® with the achieved movement measured with a final post-treatment intraoral scan or a CBCT. A summary of the inclusion and exclusion criteria is present in Table 1.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Prospective and retrospective studies on human individuals where upper incisors' positions were corrected	Studies on animals
Treatments conducted exclusively with Invisalign®	Treatments conducted with other types of clear aligners
Studies conducted in the last decade- since 2010	Systematic reviews
	Case reports or Summary articles

Search method

A similar search strategy was performed in a number of databases to include as many studies as possible. MEDLINE, Scopus, PubMed and the Cochrane Oral Health databases were searched. The results are shown in the PRISMA flow diagram (Figure 1), whilst all the search strategy and the number of articles found can be seen in the Supplementary Table 1 (Online).

Selection of studies

Once the search was made, deduplication was used with the Zotero program and, afterwards, study selection was performed by two authors first by title-reading, then by abstract-reading and finally by full-text reading. Disagreements were addressed by discussion and final discussion was resolved by the third author. The final decisions were recorded in the Supplementary Table 2 (Online).

Data extraction

Data from the selected studies was extracted by two authors and data about the study (age, number of participants, inclusion criteria, intervention and comparison group) was summarized in a PICO Table (Table 2).

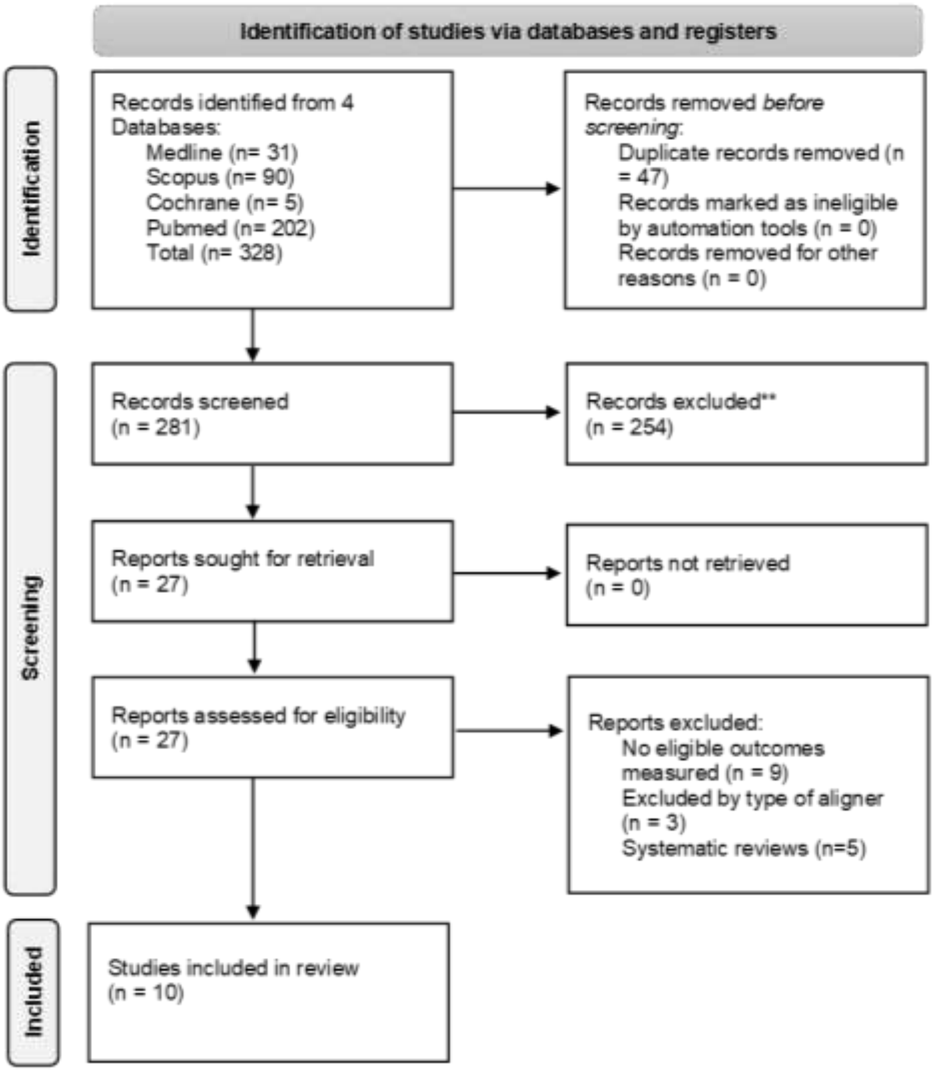

Figure 1. PRISMA Flow diagram.

Table 2. PICO table with the information from each included study (the information in the table was copied from the respective studies)

Author	Title	Study design	Participants	Age of patients (mean)	Inclusion criteria	Intervention group	Comparison group
Jiang at al, 2021	A cone-beam computed tomographic study evaluating the efficacy of incisor movement with clear aligners: Assessment of incisor pure tipping, controlled tipping, translation, and torque.	Retrospective	69 patients (44 F, 25 M)	28.565.7 years	(1) age > 20 years; (2) the presence of crowding that could be harmonized using conservative space-gaining measures such as protrusion, proclination, expansion, and interproximal enamel reduction; (3) completed treatment with the whole active stages of the first serial of aligners. Availability of 1 CBCT scan each from before and after the treatment; (4) no auxiliary device such as segmental wire and elastics was used on incisors; and (5) CBCT voxel size ranging from 0.20 mm to 0.30 mm.	69 patients (231 maxillary and mandibular incisors treated with Invisalign ®)	Final virtual 3- D Clincheck® model
Simon at al, 2014	Treatment outcome and efficacy of an aligner technique – regarding incisor torque, premolar derotation and molar distalization	Retrospective (split mouth design)	30 patients (n = 11 male, n = 19 female), 4 patients dropped out	Between 13 and 72 years, mean age 32.9 years, SD = 16.3	Healthy patients, treated with Invisalign® and one of the three following tooth movements were required: 1) upper medial incisor torque >10°, 2) premolar derotation >10°, 3) molar distalization of an upper molar >1.5 mm.	60 tooth movements (20 in each main group, 10 in each subgroup) were determined using a split-mouth design	Final virtual 3- D Clincheck® model
Karras et al, 2021	Efficacy of Invisalign attachments: A retrospective study	Retrospective	100 patients (32 males and 68 females)	mean age of 28 years 2 months- aged 11-63 years	(1) presence of optimized or conventional rotation or extrusion attachments in the planned ClinCheck; (2) completion of the initial series of aligners, resulting	382 teeth were examined with different attachments: 163 optimized rotation (43%), 72 conventional rotation (19%), 81 optimized	Final virtual 3- D Clincheck® model

					in either a refinement or final scan; (3) no planned movement of at least one posterior tooth per side of the dental arch; (4) good compliance reported with aligner wear; (5) full permanent dentition; and (6) treatment beginning in 2016 or later.	extrusion (21%), and 66 conventional extrusion (17%)	
Maree et al, 2021	Clinical expression of programmed rotation and uprighting of bilateral winged maxillary central incisors with the Invisalign appliance: A retrospective study	Retrospective	30 patients (sex not specified)	Above 18 years old	(1) bilateral WMCI at initial presentation (T1) defined as mesiopalatal rotation on visual inspection; (2) completion of prescribed initial series of aligners; (3) stereolithography (STL) files available at all 3-time points: T1, T2, and T3; (4) permanent dentition; (5) adult patients (aged .18 years); (6) nonextraction treatment; (7) treatment commenced after January 2013 with Invisalign SmartTrack aligner material exclusively; and (8) no maxillary interproximal reduction.	The pairs of incisors (60) were assessed for rotation using the interlabial angle (ILA), and individual incisors were measured for rotation and tip	Final virtual 3- D Clincheck® model
Dai et al, 2019	Comparison of achieved and predicted tooth movement of maxillary first molars and central incisors: First premolar extraction treatment with Invisalign	Retrospective	30 patients (4 males, 26 females)	Mean age 19.4 years	(1) no missing permanent maxillary teeth before treatment (except third molars), (2) the first series of aligners were finished without midcourse correction, (3) no combined treatment with fixed appliances or other auxiliary appliances, and (4) complete records of pre and posttreatment dental models.	Upper maxillary molar and central incisor movements were measured	Final virtual 3- D Clincheck® model
Haouili et al, 2020	Has Invisalign improved? A prospective	Prospective follow-up	38 patients (13 males, 25 females)	mean age of 36 years.	(1) treated with either Invisalign Full or Invisalign Teen,	899 teeth (450 maxillary and 449	Final virtual 3- D Clincheck®

	follow-up study on the efficacy of tooth movement with Invisalign				(2) underwent treatment in both arches, (3) completed an initial and final intraoral digital scan, and (4) confirmed good compliance throughout treatment.	mandibular), mesial-distal crown tip, buccal-lingual crown tip, intrusion, extrusion, and rotation of all the teeth.	model
Gaddam et al, 2021	Reliability of torque expression by the Invisalign® appliance: A retrospective study	Retrospective	40 subjects (29 females, 11 males)	Mean age 25.5yrs, SD = 3.2	Non-growing patients Complete permanent dentition Orthodontic treatment with Invisalign (SmartTrack) All subjects finished the initial aligner wear as determined by ClinCheck Two-week aligner wear protocol Simple Class I malocclusion comprising spacing (< 4 mm) to crowding (< 6 mm) Non - extraction treatment No interproximal reduction No intermaxillary elastics No orthognathic surgery No restorative treatment to incisors and distal most molars during orthodontic treatment All the subjects included in this study met the criteria of compliance	All incisors (upper and lower) torque was measured	Final virtual 3- D Clincheck® model
Grünheid et al, 2017	How accurate is Invisalign in nonextraction cases? Are predicted tooth positions achieved?	Retrospective	30 patients (13 male, 17 female)	Mean age 21.6 years	Full permanent dentition including second molars in both arches, nonextraction Invisalign treatment with no deviation from the default amounts of tooth movement embedded in each aligner stage, aligners changed every 2 weeks following the manufacturer's protocol, no	Mesial-distal, facial-lingual, and occlusal-gingival directions, as well as for tip, torque, and rotation were measured in all teeth.	Final virtual 3- D Clincheck® model

					midcourse corrections or additional aligners, and no combined treatment with fixed appliances, intraoral distalizers, or other auxiliary appliances		
Al-balaa et al, 2020	Predicted and actual outcome of anterior intrusion with Invisalign assessed with cone-beam computed tomography	Retrospective	22 patients (12 females and 10 males)	Mean age of 23.74 years (range from 16 years to 46 years 8 months).	(1) the patient underwent treatment in both arches, (2) the patient successfully completed treatment with an initial series of aligners, (3) the patient attended their appointments and had good compliance with consistent aligner wear, (4) the patient had a minimum of 1 mm or more of intrusion of the anterior teeth, (5) the patient started treatment in 2016 or later, (6) the treatment plan was nonextraction, and (7) the patient had good-quality pretreatment and posttreatment CBCT scans after the initial series	142 teeth, anterior intrusion of maxillary canines, lateral and central incisors were analyzed.	Final virtual 3- D Clincheck® model
Al-Nadawi et al, 2021	Effect of clear aligner wear protocol on the efficacy of tooth movement: A randomized clinical trial	Randomized clinical trial	80 patients divided in 3 groups of aligner protocols 7 days group: 7M/20F 10 days: 12M/13F 14 days: 11M/12F	7 days group: 36.3 10 days: 34.3 14 days: 35.4	Malocclusion to be treated with Invisalign aligners (SmartTrack) with a total initial sequence between 17 and 25 aligners, permanent dentition, good oral hygiene, and no extractions	Patients were randomly allocated into three groups: group A (7-day changes), group B (10-day changes), and group C (14-day changes)	Final virtual 3- D Clincheck® model

Measures of treatment effect

An effort was made to obtain same unit values, by converting all the results of the studies in the same unit. However, in some studies this was not possible and original results in other units were used. A detailed results table (Supplementary Table 3) (Online) was made by the two authors, whilst a table with the main outcomes is presented in Supplementary Table 4 (Online).

Missing data

Some studies did not include some data, such as the number of teeth measured, or which anterior teeth were examined. Therefore, authors were contacted, and answers were expected for a given time deadline (1 month).

Data analysis

As the data in the studies was different and different outcomes were measured, qualitative synthesis of the studies was performed as a meta-analysis could not be performed.

Quality assessment of the studies

A quality assessment was performed by two authors by using the ROBINS-I tool [4], for non-randomized controlled clinical trials (observational studies), whilst the randomized controlled clinical trials were evaluated using the Cochrane risk of bias tool.[5] The results of this analysis can be found in the Supplementary tables 5 and 6 respectively (Online). Finally, to assess the quality of evidence of the studies a GRADE assessment was performed.[6] (Table 3)

Table 3. GRADE evidence profile (quality assessment) for each analyzed objective.

Objectives (n. of studies)	Limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Large effect	Dose response	Residual confounding	Quality
Torque (4 observational, 1 RCT)	Serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	No large effect	No dose response	Would reduce a demonstrated effect	Low
Rotation (3 observational, 1 RCT)	Serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	Large effect	No dose response	Would reduce a demonstrated effect	Moderate
Intrusion (3 observational)	Serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	Large effect	No dose response	Would reduce a demonstrated effect	Moderate
Extrusion (2 observational)	Serious limitations	No serious inconsistency	No serious indirectness	No serious imprecision	Undetected	Large effect	No dose response	Would reduce a demonstrated effect	Moderate
Translation (2 observational)	Serious limitations	Serious inconsistency	No serious indirectness	No serious imprecision	Undetected	No large effect	No dose response	Would reduce a demonstrated effect	Very low

Results

In this section, the main incisors' movements will be analysed (all the results are summarized in the Supplementary Table 3 (Online).

Torque:

Regarding torque movement, Jiang et al.[7] found a mean efficiency of 31.83% (for the maxillary central incisors) and 31.70% (for the maxillary lateral incisors). Instead, Simon et al.[8] only analyzed maxillary central torque and found that there was an higher efficiency of 49.1% (with attachment) and 51.5% (with power ridge). Grünheid et al [9], instead, found a significant difference between the predicted and achieved movement in central incisors, whilst no significant difference in lateral incisors. Nadawl et al.[10] found a significant difference in both tooth types. Finally, the study by Gaddam et al.[11] analysed the torque movements by distinguishing between buccal and lingual torque and found that buccally the precision was of 21.2% (in central incisors) and of 15.5% (in lateral incisors). Lingually instead an efficiency of 116.3% (in central incisors-overcorrection) and 92.7% (in lateral incisors) was found.

Rotation:

Maxillary central incisors' rotation was analysed in the study by Maree er al.[12], where an efficiency of 71.3% was found. Grünheid et al.[9], instead, found no significant difference between the predicted and achieved movement in both central and lateral incisors, highlighting that rotation is a highly predictable movement. Nadawl et al.[10], however, found a significant difference in both teeth. Finally, the study by Haouili et al.[13] analysed the rotation movements by distinguishing between mesial and distal rotation and found that mesially the precision was of 61.1% (in central incisors) and of 53.7% (in lateral incisors). Distally, instead, an efficiency of 54.9% (in central incisors) and 54.6% (in lateral incisors) was found.

Intrusion:

Maxillary central incisors' intrusion was analysed in the study by Dai et al.[14], where an efficiency of 142.4% (overcorrection) was found. Instead, in the study by Al-Balaa et al.[15] undercorrection was found in both central (48.3%) and lateral (55.8%) incisors. Similarly, in the study by Haouili et al.[13], similar values were found: 33.4% for centrals and 53.7% for lateral incisors.

Extrusion:

Regarding extrusion movement, Karras et al.[16] found a mean efficiency of 66.3% (for the maxillary central incisors) and 46.3% (for the maxillary lateral incisors). Instead, Haouili et al.[13] found a mean efficiency of 56.4% (for the maxillary central incisors) and 53.7% (for the maxillary lateral incisors).

Translation:

Regarding translation movement, Jiang et al.[7] found a mean efficiency of 43.21% (for the maxillary central incisors) and 39.86% (for the maxillary lateral incisors). Instead, Dai et al.[14] only analysed maxillary central translation and found an efficiency of 67.71%.

Discussion

Torque:

As highlighted in the recent systematic reviews about clear aligners[1-3], the predictability of torque movements seems to be very low in most studies. Low predictability, both in the study by Jiang et al.[7] and Simon et al.[8] underlines the idea that less than 1 torque movement over 2 is predictable with the Invisalign® system (less than 50% predictability). Gaddam et al.[11] also highlighted an undercorrection in buccal torque in both incisors and an overcorrection in lingual torque. This information might be useful for dentists that could modify the digital setup overcorrecting and undercorrecting the torque prescription, so that the movement will be more predictable. However, as all these studies have a moderate ROBINS-I result, further studies, ideally randomized, should be performed to help the clinician in deciding how much to correct the setup to compensate for this over/undercorrection.

Rotation:

Concerning rotation movements, there seems to be a generally higher predictability than in torque movements (all results of the studies are higher than 50%). However, the result by Al-Nadawi et al.[10] (a randomized controlled study with a low bias) shows that there seems to be a significant difference between the predicted and achieved movement. Therefore, also this type of movement should not be considered entirely predictable and one should be extremely careful when treating the case of maxillary winged incisors (as highlighted by Maree et al.[12]).

Intrusion:

Concerning intrusion movements, there seems to be a moderately good predictability, as most results of the studies are higher than 50%. However, in the study of Haouili et al.[13] a quite low predictability for central incisor intrusion is observed (33.4%). Similarly, in the study by Dai et al.[14], an overcorrection is observed in the central incisors (142.4%). Therefore, the intrusion movement in central incisors seems to be quite imprecise and unpredictable, as this type of tooth movement seems to be either under or overcorrected depending on the study.

Extrusion:

Concerning extrusion movements, there seems to be a quite good predictability, as most results of the studies are higher than 50%. The extrusion movement is much more controllable and less potentially harmful for the soft tissues compared to the intrusion movement that could potentially result in resorption of the tooth apex if overcorrection happens. The fact that in all the studies, the extrusion movement is undercorrected is quite good for the health of the periodontal ligament during this type of movement, as the forces applied should be light, continuous and controllable.

Translation:

Concerning translation movements, a very low predictability can be observed in the study by Jiang et al (43.21% and 39.86%).[7] However, in the study by Dai et al.[14] a much higher value for central incisors is observed (67.71%). This large difference in values among studies highlights the necessity of further studies about this type of movement, that seems to be one of the hardest to perform with clear aligners.

Limitations:

In this study there were numerous limitations. Firstly, most of the studies were longitudinal or retrospective non-randomized with a moderate degree of bias. This influenced the significance of the results of most of the studies that did not justify the sample size decision. Secondly, the movements performed by the aligners were not isolated and were performed simultaneously in the teeth, so that confounding factors were present in all tooth movements measured. Thirdly, as the overall quality of the evidence was moderate, in order to translate the information found in this study in the dental practice, numerous other confounding factors would need to be taken into account, such as aligner change frequency, practitioner's expertise, pre-treatment malocclusion type and severity and attachments' shape and position.

Conclusions

- A moderate type of evidence exists regarding minor dental movements performed by the Invisalign® system. However, evidence regarding different malocclusion type correction is not present in the current literature.
- Minor dental movements seem to be predictable with the Invisalign® system, but major dental movements seem to be more unpredictable.
- The most predictable types of movements seem to be incisor rotation and extrusion, whilst the least predictable seem to be incisor torque and translation. Therefore, openbites and bilaterally winged central incisors seem to be easier to correct with the Invisalign® system than deep bites and lingually placed incisors.
- Additional evidence is needed to further confirm these conclusions and further investigate the predictability of the Invisalign® system in maxillary incisors' movements.

Ethics approval

Ethical approval was not necessary.

Consent for publication

Not necessary.

Competing/Conflicting interests

The authors declare that they have no competing or conflicting interest.

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