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Movements efficiency of the upper incisors with Invisalign® clear aligners:

A systematic review.

Athénaïs Victoria COLLARD

Dissertação conducente ao Grau de Mestre em

Medicina Dentária (Ciclo Integrado)

Gandra, 18 de dezembro de 2020

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Trabalho realizado sob a Orientação de Professora Doutora Teresa Pinho e coorientação de Mestre Aline Gonçalves

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O Orientador

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AGRADECIMENTOS

"A grateful heart is a magnet for miracles"

Thank God for all your blessings. Thank you for the serenity, the protection, and the breath of life that you give me every day. I know that you foresee a beautiful path filled with joy for me.

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Thanks to my friends, this thesis represents the end of a happy journey but with other beautiful paths in perspective by your side.

To all these persons, I offer my thanks, respect, and gratitude.

RESUMO

O objetivo da presente revisão sistemática é avaliar as evidências sobre a eficácia dos tipos de movimentos dentários realizados com os alinhadores transparentes Invisalign® nos incisivos superiores.

Uma pesquisa bibliográfica de artigos publicados foi realizada através de bancos de dados eletrônicos na Pubmed® e LILACS de janeiro de 2007 a abril de 2020, destacando a efetividade dos movimentos dos incisivos superiores com alinhadores transparentes. Seis publicações relevantes foram identificadas: cinco estudos foram retrospetivos não randomizados e um estudo prospetivo não randomizado. Nos vários movimentos realizados pelos alinhadores Invisalign® nos incisivos superiores, os movimentos são diferenciados pela previsibilidade: Os movimentos verticais têm baixa precisão enquanto que os movimentos horizontais são muito precisos. No entanto, as inovações são sempre mais promissoras em termos de eficiência e o uso de auxiliares pode aumentar a precisão dos movimentos.

Mesmo que esta revisão sistemática inclua poucos artigos, uma amostra de 547 incisivos superiores foi alcançada. Novos estudos são necessários, adequados aos avanços tecnológicos, maior retenção dos alinhadores e programação do Clincheck correta.

PALAVRAS-CHAVE

Invisalign®; Incisivo; Movimento dentário; Previsibilidade; Eficiência; Precisão.

ABSTRACT

The aim of the present systematic review is to appraise the evidence regarding the effectiveness of the sorts of tooth movements performed with Invisalign® clear aligners on the maxillary incisors.

A literature search of published trials was performed through electronic databases on Pubmed®, Cochrane library and LILACS from January 2007 to April 2020 that highlighted the accuracy of the maxillary incisors with clear aligners. Six relevant publications were identified: five studies were retrospective non-randomized, and one studies was prospective non-randomized. In the various movements performed by the Invisalign® clear aligners treatments on the upper incisors, movements are distinguished by their predictability: vertical movement have low accuracy whereas horizontal movements are very accurate. However, innovations are always more promising in terms of efficiency and the use of auxiliaries can increase the accuracy of movements.

Even if this systematic revision includes few articles, a sample of 547 upper incisors was reached. New studies are needed, adequate to technological advances, increased aligner retention, and correct set-up programming by Clincheck®.

KEYWORDS

Invisalign®; Incisor; Tooth movement; Predictability; Efficiency; Accuracy.

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1. INTRODUCTION

Invisalign® clear aligners are nowadays widely used in orthodontics, mostly in adult patients due to the improvements on aesthetics and comfort, as well as on hygiene and periodontal control (Alajmi et al., 2019 (1); Fujiyama et al, 2014(2); Iliadi et al., 2019(3); Rossini et al., 2015(4)). Since its introduction in 1997 by Align Technology®, significant improvements were developed on algorithms that can determine the necessary force systems to allow more accurate tooth movements (Morton et al., 2017(5)).

Some studies have been conducted to evaluate the movement accuracy or efficacy with Invisalign® clear aligners (Simon et al., 2014(6); Buschang et al., 2015(7); Rossini et al., 2015 (4); Grünheid et al., 2017(8); Houle et al., 2017(9); Papadimitriou et al., 2018 (10)). Significant differences were reported between predicted and achieved tooth movements, with rotation and extrusion among those that can be particularly challenging (Galan-Lopez et al., 2019(11); Rossini et al., 2015(4)). Despite the officially reported ranges for movement efficacy reported by Invisalign®, they remain far from being consensual among orthodontic professionals (Dai et al., 2019(12); Papadimitrou et al., 2018(10)), and a wide variation of accuracies can be found in the different tooth groups (Charalampakis et al., 2018(13); Simon et al., 2014(6) ;Zhou et al., 2019(14)).

To address this issue, systematic reviews (Galan-Lopez et al., 2019(11); Papadimitrou et al., 2018(10); Rossini et al., 2015(4)) evaluating the accuracy and effectiveness of Invisalign® clear aligners were published in the last five years. However, the conclusions were drawn regarding the type of movement and not according to a specific tooth or tooth group.

Accordingly, it is still difficult to assess specific clinical concerns such as those associated to upper incisors.

Therefore, the aim of the present systematic review is to answer the question: What is the accuracy and the efficiency of the various tooth movements performed on maxillary incisors with Invisalign® clear aligners?

2. MATERIALS AND METHODS

2.1. Protocol and registration

This systematic review followed the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) checklist (15). The protocol was registered in the PROSPERO database (CRD42020190272).

2.2. Identification of relevant studies

Articles that compare the predicted with the achieved tooth movements while using Invisalign® clear aligners were included. A systematic search was performed for articles published between January 2007 and April 2020 with language restricted to English, French, Spanish or Portuguese.

The PICOS (participants, intervention, comparison, outcomes, study design) approach was used to establish the primary inclusion criteria for the studies: (1) Participants: patients with permanent teeth undergoing treatment with Invisalign® clear aligners; (2) Intervention: orthodontic treatment with Invisalign® clear aligners; (3) Comparison: predicted versus achieved tooth positioning; (4) Outcome: Clinical accuracy and efficacy among the tooth

movements performed with Invisalign® clear aligners on upper incisors; (5) Study design : controlled clinical trials (randomized or not), cohort studies, case control studies and case series. Prospective, retrospective, and cross-sectional studies were also considered.

2.3. Information sources and search strategy

Before starting the search on selected databases, the search strategy was discussed among all authors of this article. Comprehensive searches were made from January 2007 and April 2020 in the following databases: PubMed, LILACS, Scopus, Cochrane Library and Web of Science.

The lower limit for the year was defined according to the introduction of optimized aligner features by Invisalign, in order to improve tooth movement accuracy.

The search strategy comprised the use of the following terms: "(Humans* OR adult* OR malocclusion* OR male* OR female*) AND (Invisalign OR clear aligners OR aligners OR transparent aligners OR orthodontic appliances, removable*) AND (cephalometry* OR orthodontic treatment OR treatment outcome*) AND (incisor* OR incisors)."

Additionally, a manual search was conducted in orthodontic journals of interest, such as the American Journal of Orthodontics, European Journal of Orthodontics, The Angle Orthodontist, Journal of Orthodontics.

2.4. Study selection and data collection

Three reviewers (DM, AC, AG) independently selected the articles for analysis. In case of disagreement the other authors (TP, RA) intervened. The same methodology was then used to process the articles through the previously set criteria for inclusion and exclusion, after the duplicates were removed. The titles were analyzed, followed by the reading of the

abstract and the full article. References of selected articles were subjected to a detailed search for potentially relevant studies.

2.5. Data Items

Data collected from each article included: author, year of publication, study design, participants, type of intervention, and results *Table 1*.

Table 1: Overview of Design, participants, type of intervention, and results of the included studies.

Study	Study design	Participants	Invisible Aligners		Results		
			Type	Intervention	General	Upper central incisors	Upper lateral incisors
Kravitz et al., 2009. (18)	Prospective clinical study.	37 pts. -225 Maxillary central incisors. -240 Maxillary lateral incisors	Invisalign®	-Pre- and posttreatment digital models.	-Mean accuracy of tooth movement: 41%. -Most accurate movement: Lingual constriction (47.1%). -Least accurate movement: extrusion (29.6%). -Mean accuracy of intrusion: 41.3%. -Mean intrusion: 0.72mm.	Mean accuracy of the movement: -Rotation: 54.2%. -Labial expansion: 48.5%. -Lingual constriction: 51.8%. -Intrusion: 44.7%. -Extrusion: 18.3%. -TIP (MD): 38.6%. -TIP (LL): 40.3%.	Mean accuracy of the movement: -Rotation: 43.4%. -Labial expansion: 49.0%. -Lingual constriction: 40.4%. -Intrusion: 32.5%. -Extrusion: 28.4%. -TIP (MD): 43.1%. -TIP (LL): 47.6%.
Castroflorio et al., 2013. (19)	Prospective.	6 pts. -9 Maxillary incisors.	Invisalign®	-Pre- and posttreatment digital models.	-Differences between virtual (Clincheck®) and real measurement are insignificant.	Mean differences Between Predicted and Achieved Tooth Positions: -Torque with Power Ridge®: 0.02°.	N. A

						UNTIL 10° OF TORQUE PRESCRIPTION	
Simon et al., 2014. (6)	Retrospective clinical study.	30 pts. -20 Maxillary incisors (10 with Power Ridge®, 10 with attachment®)	Invisalign®	-Pre- and post-treatment casts. -Movement accuracy study: torque with Power Ridge® and attachment.	-Mean efficacy of tooth movement: 59.3%	Mean accuracy of the movement: -Torque with Power Ridge: 51.5%. -Torque with Attachment: 49.1%.	N.A
Grunheid et al. 2016. (8)	Retrospective cohort study.	30 pts. -60 Maxillary central incisors. -60 Maxillary lateral incisors	Invisalign®	-Pre- and posttreatment digital models.	-Statistically significant differences (P <.05) between predicted and achieved tooth positions were found for all teeth except maxillary lateral incisors. -Anterior teeth were positioned more occlusally than predicted. -Anterior teeth had an excess of extrusion.	Mean differences Between Predicted and Achieved Tooth Positions: -Rotation: -0.33° -Torque: 1.75° -TIP (LL): 0.42° -Facial/Lingual: -0.45mm -Mesial/Distal: -0.06mm -Occlusal/Gingival: -0.30mm	Mean differences Between Predicted and Achieved Tooth Positions: -Rotation: 0.70° -Torque: 0.08° -TIP (LL): 0,35° -Facial/Lingual: 0.01mm

							-Mesial/Distal: -0.14mm -Occlusal/Gingival: -0.03mm -Occlusal-gingival position or torque: Accurate
Charalampakis et al. 2018.(13)	Retrospective clinical study.	20 pts. -80 Maxillary incisors.	Invisalign®	-Pre- and posttreatment digital models.	-Vertical movements present discrepancies between the completed and predicted position. -The completed rotation movements are always lower than those predicted.	Mean differences Between Predicted and Achieved -Horizontal movements:0.25mm -Extrusion: -0.30mm Accurate. -Intrusion: 1.50mm. Inaccurate. -Rotation: 2.00°.	Mean accuracy of the movement: -Horizontal movements: 0.25mm. Accurate. -Extrusion: -0.25mm Accurate. -Intrusion: 1.10mm. Inaccurate. -Rotation: 1.85°.
Dai et al., 2019. (12)	Retrospective.	30 pts. -120 Maxillary central incisors.	Invisalign®	-Pre- and posttreatment digital models.	N. A	Mean differences Between Predicted and Achieved Tooth Positions: **translação** -TIP (LL): -5.16°	N. A

				-ClinCheck® initial and final virtual setups.		-Facial/Lingual: 2.12mm -Occlusal/Gingival: -0.50mm.	
Haouilli et al., 2020 (17)	Prospective clinical study.	29 pts. -116 Maxillary incisors			-Mean accuracy for all tooth movements: 50%. -Highest accuracy: buccal-lingual crown tip (56%). -Lowest accuracy: rotation (46%).	Mean accuracy of the movement: -Mesial rotation: 61.1%. -Distal rotation: 54.9%. -Intrusion: 33.4% -Extrusion: 56.4% -TIP (MD): 57.5% (mesial) / 49.8% (distal). -TIP (LL): 57.4% (lingual) / 54.2% (labial).	Mean accuracy of the movement: -Mesial rotation: 54.6%. -Distal rotation: 48.7%. -Intrusion: 44.6%. -Extrusion: 53.7%. -TIP (MD): 47.3% (mesial) / 47.3% (distal). -TIP (LL): 54.4% (lingual) / 69.9% (labial).

Table 1: Overview of Design, participants, type of intervention, and results of the included studies.

2.6. Risk of bias (RoB) and quality assessment in the studies

After data collection, two independent reviewers (AC and AG) assessed the potential risk of bias of the included studies according to non-randomized studies of interventions tool ROBINS-I (16). This tool is based on seven domains that include: (1) bias due to confounding, (2) bias in selection of participants into the study, (3) bias in classification of interventions, (4) bias due to deviations from intended interventions (5) bias due to missing data, (6) bias in measurement of outcomes, (7) bias in selection of the reported result, and (8) overall bias].

Bias assessments were tabulated with explanations when studies were downgraded. Since assessments are inherently subjective and there are no strict and objective criteria to judge bias within the ROBINS-I tool, disagreements were resolved via discussion between the two investigators. Bias was assessed per study rather than per outcome since there were no meaningful differences in bias across outcomes.

3. RESULTS

3.1. Study selection

The electronic search initially identified 291 relevant articles. After 53 duplicates' removal, 238 papers remained. Seventy-one papers were assessed for screening, and after abstract-reading, 167 studies were excluded leaving 12 articles to be read in full-text. After the application of specific inclusion and exclusion criteria, another 6 articles were removed. Six studies were considered eligible for inclusion in the final analysis. One study was included from the manual search. In total, seven studies were included in the systematic review. The selection of articles included in this systematic review are shown in the PRISMA flow chart Figure 1.

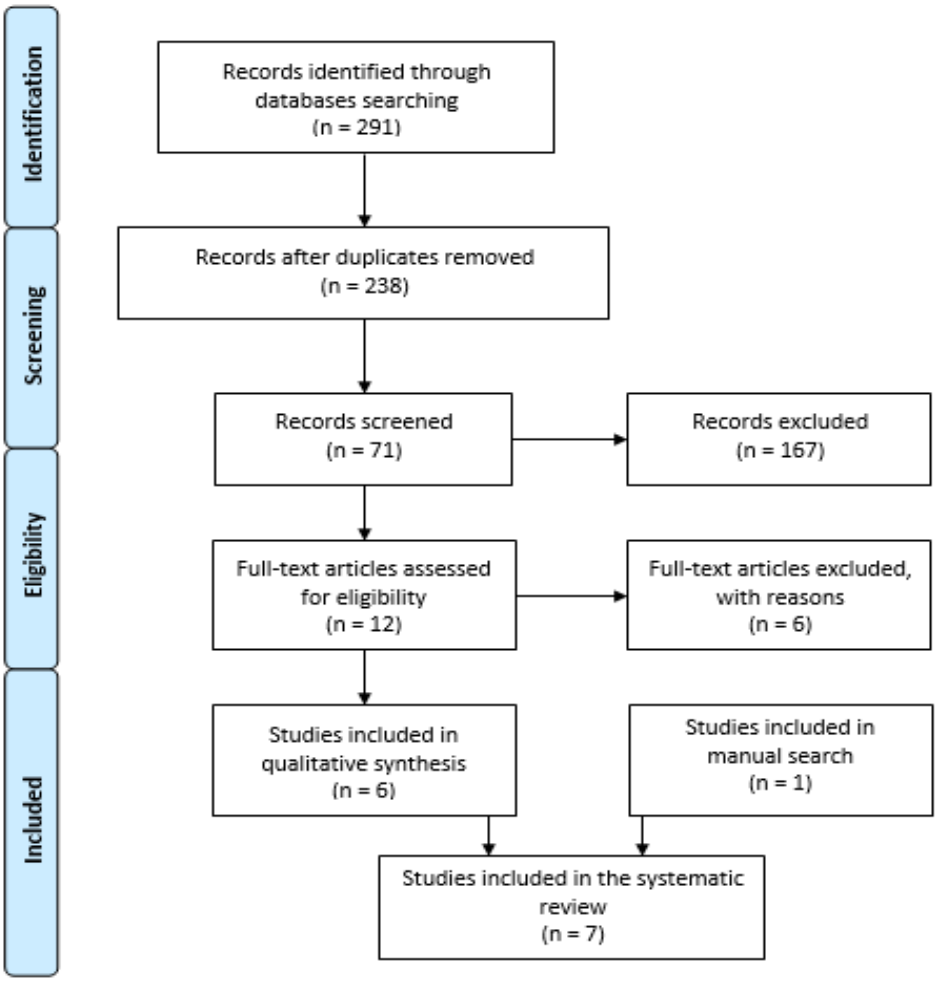

Figure 1: Studies' flow diagram

3.2. Study characteristics

Seven relevant publications were identified: four studies were retrospective non-randomized, and three studies were prospective non-randomized. There were variations in the total sample size (range 6–37 patients), totalizing 1110 studied movements with upper incisors. All treatments were carried out with Invisalign® clear aligners. However, the results were written either as an accuracy percentage or as a difference in accuracy (difference between achieved and predicted tooth position). Therefore, the data from two articles (8, 13) where the results were described in terms of a difference in accuracy, were converted into percentage, to allow the comparison among them. Two (6, 17) of the covered studies assessed predictability of tooth movement comparing posttreatment patient models to the predicted digital planned tooth movement models [(ClinCheck®) (Vectra, Canfield Scientific, Fairfield, NJ, USA software)]. Two studies (8, 18) used Tooth Measure software, application developed by Align Technology, to score the discrepancy index (DI) virtual model of the predicted tooth position superimposed over the virtual model of the achieved tooth position. One study (12) superimposed the pretreatment model with the virtual posttreatment model without mentioning the software used. Another study (13) used the 3-dimensional Image Analysis open-source softwareSlicer CMF to superimpose the predicted and achieved models. Finally, a study (19) used three-dimensional (3D) scans of the initial and final plaster casts.

3.3. Assessment of risk of bias (RoB)

Among the included studies, four studies had a high RoB (6, 13, 17, 18), four other studies have a moderate risk of bias (8, 12, 19, 20) Table 2.

Table 2: Risk of bias of observational studies by ROBINS-I quality assessment scale								
	Domains							**Overall RoB Judgment**
	Preintervention		**Intervention**	**Postintervention**				
Authors	**Bias due to Confounding**	**Bias in Selecting Participants for the Study**	**Bias in Classifying Interventions**	**Bias due to Deviations from Intended Intervention**	**Bias due to Missing Data**	**Bias in Measuring Outcomes**	**Bias in Selecting Reported Result**	
Karwitz et al., 2009								
Castroflorio et al., 2013								
Simon et al., 2014								
Grunheid et al., 2016								
Charalampakis et al., 2018								
Dai et al., 2019								
Haouilli et al., 2020								
Low; Moderate; Serious risk of bias								

Table 2: Risk of bias of observational studies by ROBINS-I quality assessment scale

Risk of bias from confounding was considered critical when confounding was not inherently controlled for (i.e. no or limited adjustment).

Selection bias was critical when selection into the study was very strongly related to intervention and outcome. This occurred when researcher decides who is going to be studied (18) or when the patients selected had already a refinement goal (13). This bias is minimal when the patients were prospectively selected (19).

Most of the studies did not report any missing data and were therefore classified as low risk of bias, but the risk of bias could also be considered "unknown". However, two studies (6, 17) were at high risk of bias for missing data due to the "drop off" of patients.

All studies were at moderate risk for selective reporting since none provided a pre-registered protocol.

The measurement biases are low when the measurements of the study are carried out by people external to the study, and without knowledge of the objectives. Thus, studies 19 (independent laboratory) and 20 (independent researchers) have a low risk of measurement bias. On the other hand, in study 13, the measurements are carried out internally, with the desire to make a refinement from the beginning of the study, which can influence the measurement.

The remaining ROBINS-I domains were all judged to be at low risk of bias.

3.4. Effects of Intervention

Torque: The accuracy of the movement for central incisors ranged from 49.1 to 55.6% (6, 12), and statistically significant differences between predicted and achieved position were

found (6, 8). However, a study (19) found 99% of accuracy in torque movement for upper central incisors. Significant differences were not found for lateral incisors (8).

Buccal-Lingual Tip: The bucco-lingual tip ranged from 40.3% to 57.4% on upper central incisors and 47.6% to 69.9% for upper lateral incisors, without statistically significant difference between buccal or lingual direction (17, 20).

Mesiodistal Tip: The accuracy mesiodistal tip movement ranged from 38.6% to 57.5% on upper central incisors and from 43.1% to 47.3% for upper lateral incisors (17, 20), without statistically significant difference between mesial or distal direction(8, 17, 20) . Statistically significant differences between predicted and achieved tooth movement were not found by Grunheid et al (8).

Intrusion and Extrusion: The accuracy ranged from 33.4% to 57.4% for intrusion and 18.3% and 56.4% for extrusion movement on upper central incisors, and 32.5% to 44.6% for intrusion and 28.4% to 53.7% for extrusion on upper lateral incisors (17, 20). Statistically significant differences between achieved and predicted tooth movement were found for occlusal-gingival movements in central incisors but not for the lateral incisors by two studies (8, 12). However, Charalampakis et. al (13) found statistical significant differences in intrusion movement on both teeth.

Rotation: The accuracy ranged from 42.75% to 61.1% for central incisors and 33.44% and 54.6% for lateral incisors (12, 17, 20). Statistically significant differences between predicted and achieved movements were found in one study (13), but not in the other study (8). Moreover, a statistically significant difference between mesial and distal rotation was not found.

Labial-lingual Translation: The accuracy of labial translation ranged from 32.27% and 48.5% for CI and only one study evaluated 49.9% for central and lateral incisors respectively, and 51.8% and 40.4% for lingual translation (12, 17, 20). Statistically significant differences between predicted and achieved movements were found by Grunheid et. al. (8) for central incisors but not for lateral incisors.

Mesial-Distal Translation: Only one study evaluated the mesial-distal translation of incisors, without statistically significant differences between predicted and achieved tooth.

4. DISCUSSION

The current scientific evidence should be considered in the understanding of the limitations of the appliance in order to achieve the desired clinical outcomes. Since its creation, clinicians have reported clinical issues associated with the movement of the upper incisors that fail to reach the programmed positioning. Accordingly, continuous innovations of Invisalign® clear aligners specifically associated to the upper incisors, suggest the necessity to increase the movement accuracy. However, the movement accuracy is dependent of several factors beyond the appliance technology, which influences the analysis of the results. To complicate matters further, in the literature only some movements are analyzed in each study, representing very limited datasets. In addition, some reports use averages, others medians, which associated with small sample sizes (ref) and the presence of outliers, could represent accuracy values which are difficult to interpret and cross compare.

4.1. Axial movements: torque and tip:

The admeasurement of torque must be clearly defined according to the correct definition

of the term torque. The word torque is frequently used to express a crown axial inclination, the clinical torque, defined by a perpendicular line to the dental margin and passing through the facial axis crown (Lacarbonara et al., 2015 (21). From the biomechanical point of view, torque is couple force system or a pure moment, that cannot be represented by a clinical evaluation (Burstone and Choy, 2015(22)). Two studies (12, 19) evaluated the clinical torque due to the facial inclination of the buccal surface. Castroflorio et.al (19) found a negligible torque loss on upper central incisors, with a 99.0% of accuracy of torque movement. Nonetheless, the sample reports to 9 upper incisors with an evaluated movement until 10 degrees of clinical buccal torque. This finding contrasts with an accuracy of 55.66% with a statistically significant difference between predicted and achieved tooth movement found by Dai et al (12). It should be emphasized that this study evaluated the accuracy of incisors movement on a bicuspid extraction protocol, that rises clinical issues that compromise the evaluation of a single movement, as well as any aligner feature was used in regard incisor movement improvement.

Statistically significant differences between predicted and achieved tooth positions were found in two studies (6, 8), in which the latter reported an accuracy of 49.1% (with horizontal ellipsoid attachment) to 51.5%, with power ridges. Despite the accordance between these two authors, different methods were used to compare the predicted and achieved tooth positioning, and the exact definition of the term torque is not totally clear. Furthermore, the reference point was determined in regard the virtual crown positioning without root change evaluation and when biomechanical torque evaluation is considered these finding might be interpreted with caution.

Haouilli et. al (17) excluded the torque measurement due to the absence of radiographs, whereas Kravitz et. Al (20) assumed the clinical torque as a labiolingual tip. These findings

illustrate the frequently misuse of the term torque. Even though, they evaluate the accuracy of buccal-lingual tip with higher values on lateral incisors. They found the highest rate for buccal tip on lateral incisors (69.9%) (17), despite the small clinical crown has been reported as the main factor for loss of retention and movement failure throughout the treatment (23, 24). Moreover, the accuracy of buccal-lingual movement increase from 40.3% / 47.6% (20) to 55.8% / 62.15% (values correspond to the average of buccal and lingual tip presented separately by the authors) for central and lateral incisors respectively (17). These findings can be related to the aligner material or to improved features on Invisalign aligners.

The mesio-distal tip ranged from 38.6% to 57.5% on upper central incisors and from 43.1% to 47.3% on upper lateral incisors, without statistically significant differences between mesial or distal direction (17, 20) or predicted and achieved tooth movements (8).

4.2. Vertical movements: extrusion and intrusion

Tooth extrusion was reported as the least accurate movement (18.3% CI and 28.4% for LI) with Invisalign (20). However, the study developed by Haouilli et.al (17) 10 years later, revealed an increased accuracy of 56.6% for CI and 53.8% for LI, which is expected due to improvements on the features of Invisalign aligners, such as optimized extrusion attachments. Even though, statistically significant difference between predicted and achieved tooth positioning was found for CI, but not for LI.

Interestingly, the intrusion movement accuracy for CI decreased (44.7% (20) to 33.4% (17)), but increased for LI incisors (32.5% (20) to 44.6% (17)). Despite the development of optimized attachments to improve aligner grip for a more reliable intrusion, attachment hierarchy might interfere with its placement and with the movement. Moreover, Charalampakis et. Al (13) found negative values for incisor intrusion, that means that

extrusion movement was achieved when intrusion movement was programed. The authors reported that, despite the tooth superimposition was based on unmovable teeth the bite block effect promoted some molar intrusion and was responsible for the negative value (13). For the same reason, the extrusion movement appeared increased due to the same reasons and did not allow the vertical movement evaluation (13). Grunheid et al., 2017 (8) found statistically significant differences for occluso-gingival movements on CI that are in agreement with the low accuracies found in other studies (12, 17, 20). Furthermore, given the low predictability of the extrusion movement, Grunheid (8) recommend that this movement should be left for the final stages of the treatment and combined with more precise movements such as retraction.

4.3. Horizontal movements: rotation, mesial-distal and labiolingual translation

Regarding horizontal movements, rotation movements ranged from 54.2% to 61.1% for CI and 43.4% to 66.15% for LI (12, 17, 20). The accuracy is lower for LI than for CI which could be related to the small clinical crown. Consequently, the small distance between the point of application of the forces also generates smaller moments.

The accuracy of rotation movements has increased in more recent studies and presents the highest values among the different evaluated teeth, which can be explained by their flat morphology. Statistically significant differences between predicted and achieved tooth positioning were not found on incisors rotation (8).

The accuracy of labial translation of incisors was only measured in one study with 48.5% and 49.0% for CI and LI respectively (20). The same author reported values for lingual translation of 51.8% and 40.4% for CI and LI respectively, however Dai et.al (12) found an accuracy of 67.7% for CI with lingual inclination as a side effect. Grunheid et. al (8) found

statistically significant differences between predicted and achieved movements for CI but not for LI. Despite the aligner material innovations, these findings are not surprising since labial and lingual tooth provider larger surfaces for the appliance to apply forces.

5. LIMITATIONS

Very few articles met the objective of this systematic review. As a result, a rigorous methodology for researching the biases of each of the selected studies has been implemented. No RCT could be included. It is important to note that for this literature review, the articles selected range from 2009 (20) to 2020 (17). Invisalign® G2 aligners were used before 2009.

6. CONCLUSIONS

Conclusions from these studies led to significant improvements with regards to the material used and the planning and realization of tooth movement with aligners.

- The accuracy of the tooth movements for the upper incisors ranges from 18.3% to 85%.
- For the upper central incisors: the horizontal movements (especially rotation) were the most predictable movements whereas the vertical movements were the less predictable.
- For the upper lateral incisors: the horizontal movements (especially Labiolingual tipping) were the most predictable movements whereas the vertical movements were the less predictable.

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8. TABLE OF CONTENTS

9. ANNEXS

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Movement efficiency of the upper incisors with Invisalign® clear aligners: a systematic review.	
ABSTRACT			
Structured summary	2	The aim of the present systematic review is to appraise the evidence regarding the effectiveness of the sorts of tooth movements performed with Invisalign® clear aligners on the maxillary incisors. A literature search of published trials was performed through electronic databases on Pubmed®, Cochrane library and LILACS from January 2007 to April 2020 that highlighted the accuracy of the maxillary incisors with clear aligners. Six relevant publications were identified: five studies were retrospective non-randomized, and one studies was prospective non-randomized. In the various movements performed by the Invisalign® clear aligners treatments on the upper incisors, movements are distinguished by their predictability: vertical movement have low accuracy whereas horizontal movements are very accurate. However, innovations are always more promising in terms of efficiency and the use of auxiliaries can increase the accuracy of movements. Even if this systematic revision includes few articles, a sample of 547 upper incisors was reached. New studies are needed, adequate to technological advances, increased aligner retention, and correct set-up programming by Clincheck®. **KEYWORDS** Invisalign®; Incisor; Tooth movement; Predictability; Efficiency; Accuracy.	VII - IX
INTRODUCTION			
Rationale	3	Invisalign® clear aligners are nowadays widely used in orthodontics, mostly in adult patients due to the improvements on aesthetic and comfort, as well as of the hygiene and periodontal control. Since its introduction in 1997 by Align Technology®, relevant improvements were developed based on algorithms, able to determine force systems to allow more accurate tooth movements. Several studies have been tried to evaluate the accuracy and effectiveness of the movement with Invisalign® clear aligners. Significant differences were reported among predicted and achieved tooth movements wherein movements such as rotation and extrusion can be particularly challenging	1

		while using clear aligners. Despite the ranges of movement assessment reported by Invisalign®, the movement effectiveness remains far from being consensual among orthodontic professionals, as well as a wide variation of movement accuracy can be found in the different tooth groups.	
Objectives	4	Therefore, the aim of the present systematic review is to answer the question: What is the accuracy and the efficiency of the various tooth movements performed on maxillary incisors with Invisalign® clear aligners?	1
METHODS			
Protocol and registration	5	The Preferred Reporting Item for Systematic Review and Meta-Analysis (PRISMA) checklist [1]was used as a guideline for conducting and reporting the present review. **Participants:** Adult patients with permanent teeth using Invisalign®. **Intervention:** Orthodontic treatment with Invisalign® clear aligners. **Comparison:** Predicted versus achieved tooth positioning. **Outcomes:** Any effect on clinical efficiency, effectiveness, treatment outcomes, movement accuracy on upper incisors as primary outcomes. **Study design**: Randomized clinical trials (RCTs), controlled clinical trials (CCTs), cohort studies.	2
Eligibility criteria	6	Inclusion criteria: Articles published between 2007 and 2020 in English only. Exclusion criteria: Articles published in languages other than English; Any studies not pertaining to the question of Invisalign® treatment effectiveness.	2
Information sources	7	PubMed (via the National Library of Medicine) and LILACS (1982 to September 2016) databases.	2
Search	8	The strategy used was a combination of Mesh terms and free text words: • Intervention: Invisalign [Text word] OR orthodontic treatment [MeSH Terms] AND • Comparison: incisors [MeSH Terms] AND • Outcomes: treatment outcome [MeSH Terms] OR (efficiency [MeSH Terms] OR accuracy [Text word] OR predictability [Text word] AND • Study design: longitudinal study [MeSH Terms] OR randomized controlled trial [MeSH Terms] OR clinical trial [MeSH Terms] OR prospective study [Mesh Terms] OR retrospective study.	3

Study selection	9	Stage I: A computerized search was conducted using PubMed (via the National Library of Medicine), from January 2009 to December 2019. Preliminary review of the abstracts, accessible studies, titles was performed to determine if the articles met the intended purpose for the study. Articles compiled by combining keywords and duplicates were removed using the Mendeley citation manager. If the study did not meet the inclusion criteria, exclusion was indicated. Any studies not published in English were excluded from the study. Stage II: Quality assessment was performed on the studies that fulfilled the inclusion criteria. The quality and design of the study was considered. Stage III: Of the studies that passed the quality assessment stage, a thorough evaluation was completed. Summaries of the included articles were prepared and information regarding study design, subjects, treatment time, and outcomes were organized in tabulated form.	3
Data collection process	10	Overall, of the 291 studies reviewed (Stage I), 24 were selected for further review (Stage II). Ultimately, 6 studies were included in the systematic review (Stage III).	3
Data items	11	Six relevant publications were identified: five studies were retrospective non-randomized, and one study was prospective non-randomized.	3
Risk of bias in individual studies	12	Not done	
Summary measures	13	Not done	
Synthesis of results	14	Not done	

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Not done	
Additional analyses	16	Data from four articles where the results were described in terms of a difference in accuracy, were converted into percentage, to allow the comparison among them.	
RESULTS			
Study selection	17	The remaining potentially relevant 24 studies were then evaluated. Of those studies, 5 were excluded because they did not provide comprehensive data considering the purpose of the present study. Therefore, a total of 13 studies were included in our review. Overall, of the 24 studies reviewed (Stage I), 19 were selected for further review (Stage II). Ultimately, 13 studies were included in the systematic review (Stage III).	5

Study characteristics	18	Of the 14 studies selected, 8 (57.1%) investigated the accuracy and the predictability of the movements with the system Invisalign®. Two other articles (14.2%) evaluated the efficacity and effectiveness of Invisalign® regarding the tooth movements while three studies (21.4%) assessed specific movements of the lateral incisors and one article (7.1%) selected because of its interesting clinical cases.	5
Risk of bias within studies	19	Not done	
Results of individual studies	20		6-8
Synthesis of results	21		6-8
Risk of bias across studies	22	Not done	
Additional analysis	23	None	
DISCUSSION			
Summary of evidence	24	Because of the retention loss, vertical movements are particularly challenging for aligner systems such as Invisalign®. In fact, the aligner suffers from a lack of anchoring when it comes to vertical movements due to poor retention over the crown. The extrusion movement is the least accurate movement with the Invisalign® system. The accuracy ranged from 18,3% (Karwitz et al., 2009) to 42,30% (Dai et al., 2019), that are in accordance with other studies (Grunheid et al., 2017; Charalampakis et al., 2018). The intrusion accuracy is the lowest for the upper lateral incisors (Karwitz et al.): 32,5%, and slightly higher for the central incisors (44.7%). The least intrusion accuracy was with the superior lateral incisor probably due to the force generated by the imposing crowns and roots of the adjacent canine and central incisor. Regarding horizontal movements, the accuracy of the rotation ranged from 28,46% (Charalampakis et al.) to 54,20% (Karwitz et al.). The accuracy of the upper lateral incisor is significantly lower than that of all other incisors. This can be explained by the narrow clinical crown of the upper lateral incisor which provides only a small contact surface with the aligner, as well as this tooth is between two big and strong teeth like canine and central incisor, it look like this tooth is lost in aligner, because the aligner doesn't catch the tooth. As for the mesiodistal translation, two studies (Grunheid et al.; Charalampakis et al.) confirm the accuracy of this movement with Invisalign®. Several studies (Karwitz et al., 2009; Grunheid et al., 2017; Dai et al., 2019) have shown a great accuracy of the lingual and labial translations. Axial movements result to be predictable with Invisalign®. The accuracy of the torque movement ranged from 49,1% (with horizontal ellipsoid attachment) to 51,5%, with power ridges (Simon et al.) for the upper central incisors. The results are in accordance with other studies (Castroflorio et al.; Grunheid et al.). Regarding the tip movement, the accuracy ranges from 38.6% to 47.6% (Karwitz). The accuracy of the mesiodistal movement is 38.6% and 43.1% for the upper central and lateral incisors, respectively. About the labiolingual crown tip, the accuracy is higher and has less discrepancy compared to the other teeth. Indeed, this represents the greatest accuracy for all movements of the upper lateral incisors, about 47,6% (Karwitz).	9-13

Limitations	25	Of the six articles selected, five are retrospective studies which makes it possible to test the accuracy of movements between the positions of the predicted teeth with those obtained. On the other hand, sampling biases can interfere in the study, just as patient adhesion is difficult to determine. Also, patient compliance during the Invisalign® process is fundamental for a successful treatment. It is important to note that for this literature review, the articles selected range from 2009 (Karwitz) to 2019 (Dai). The aligner material that was used back in 2009 was from the Invisalign® G2 aligners. Conclusions from these studies led to significant improvements with regards to the material used and the planning and realization of tooth movement with aligners. The aligners being used now are Invisalign® G5, that is 3 generations ahead. This does not mean that all the problems are fixed, but we can pretend that Invisalign® G5 aligners have better efficacy than Invisalign® G2 aligners.	9-13
Conclusions	26	In the present systematic review, only six studies were found regarding specifically and quantitatively the accuracy of various movements for the upper incisors. There are sparsely quantitative researches on the predictability and the accuracy of movements for each tooth, particularly over the last five years, in correlation with the new technique's advances, the latest materials and the latest software. However, given the lack of research regarding the maxillary incisors' tooth movement with Invisalign® treatment, this systematic review was enough for the purposes whereby the attained sample is 547 upper incisors. ▪ The accuracy of the tooth movements for the upper incisors ranges from 18.3% to 85%. • Rotation movement was the most predictable movement for the upper central incisors. • Labiolingual tipping was the most predictable movement for the upper lateral incisors. • The extrusion movement was the less predicted movement for both upper incisors.	14
FUNDING			
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