

Predictability of Aligners in Incisor Extrusion and Molar Intrusion Movements: A Systematic Review of in Vitro Studies

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Abstract

Background: Aligners, commonly used in orthodontic treatments, have shown varying degrees of effectiveness depending on the type of tooth movement required. This systematic review will outline recent findings and updates regarding the predictability of aligners in incisor extrusion and molar intrusion movements. **Objective:** The purpose of this study was to systematically review the literature and evaluate the predictability of clear aligners in incisor extrusion and molar intrusion movements based on the available evidence. **Materials and Methods:** A total of three databases (Pubmed, Sciences Direct and Google Scholar) were searched until March 2023, in addition to a manual search in the following journals: the American Journal of Orthodontics and Dentofacial Orthopedics, The Angle Orthodontist, and the European Journal of Orthodontics. Finite elements studies assessing the ability of aligners in achieving incisor extrusion and molar intrusion movements published during the last 10 years in English were eligible to be selected. Study selection and data extraction were undertaken independently by two reviewers. Risk-of-bias (RoB) assessment was evaluated using the Methodological Quality of Single Subject Finite Element Analysis. The reporting of this review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. **Results:** Four pertinent articles were incorporated into the analysis, all of which are finite element studies. Among these, three studies assessed the efficacy of aligners in achieving incisor extrusion, while one solely examined their predictability in molar intrusion. The risk of bias was categorized moderate in all studies. All these studies have agreed that attachments are essential for achieving incisor extrusion and molar intrusion movements. In fact, the position of the attachment has a greater influence on the amount of movement than its shape. **Conclusion:** The use of attachments has proven to be crucial for successfully achieving vertical movements with aligners. Horizontal rectangular palatal attachments are essential for incisor extrusion, while a combination of buccal and palatal attachments is necessary for molar intrusion.

Keywords: Clear Aligners, Invisible Orthodontics, in Vitro Studies, Extrusion, Intrusion, Vertical Dimension.

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INTRODUCTION

Aligners have revolutionized orthodontic treatment by offering a more discreet and comfortable alternative to traditional braces. These clear, removable devices are custom-made to fit snugly over the teeth and gradually shift them into the desired position. The introduction of aligners has significantly impacted the field of orthodontics, providing patients with an

aesthetically pleasing option that also maintains oral hygiene more effectively than conventional braces.

Initially, aligner therapy was employed to correct minor crowding or close diastemas. However, advances in aligner materials, attachment designs, and 3D software now allow for the treatment of various types of malocclusions [1].

More recently, some practitioners have started using aligners to control vertical dimension, raising the possibility of developing posterior open bites at the end of aligner treatment [2].

With the series of improvements introduced in recent years, such as the Invisalign G series, several clinical case reports using aligners have demonstrated good vertical control.

In this context, we undertook this systematic review to evaluate the effectiveness of aligners in incisor

extrusion and molar intrusion movements. It is structured into four main sections: Introduction, Materials and Methods, Results, and Discussion (IMRaD structure).

2. MATERIELS AND METHODS

2.1 Eligibility Criteria

The PICOS (population, intervention, comparison, outcome, study design) format was used to formulate the clinical question with defined inclusion and exclusion criteria (Table 1). All articles included in this systematic review met the following criteria.

Table 1 : Eligibility criteria

Domains	Inclusion Criteria	Exclusion Criteria
Participants	Models for simulated tooth movement with aligners.	In vivo studies.
Intervention	All types of aligners used for orthodontic tooth movement were considered eligible, irrespective of material type, thickness and activation.	Conventional orthodontic treatment, orthognathic surgery treatment.
Comparaision	Any type of comparator will be considered, either non-aligner or- thodontic devices or different types of aligners (in terms of design, thickness, inclusion of attachments).	
Outcome	Forces and/or moments generated, complying with incisor extrusion or molar intrusion.	Any other type of movement.
Study design	In vitro/laboratory studies, studies related to the forces/moments exerted by aligners, Finite Element Studies.	Systematic review, Narrative review, Non-original article, Letters to the Editor, Case report, Cohort study, Case series, before-after studies.

2.2 Information Sources and Search

Two reviewers independently conducted a comprehensive search using a combination of controlled vocabulary (MeSH) and free text terms. PubMed, Sciences Direct and Google Scholar were searched from

January 2013 to March 2023. Only english articles were included. Keywords used in search were : “Clear aligners”, “Invisible orthodontics”, “Anterior open-bite”, “Incisor Extrusion”, “Molar Intrusion”, “Vertical dimension” (Table 2).

Table 2 : Details of the database search Database Search Strategy

Database	Search Strategy
Pubmed	Orthodontics AND (“orthodontic appliances, removable” OR “removable orthodontic appliances”) AND (“clear aligners” OR (“clear” AND “aligners”) AND aligners AND (“therapy” OR “treating”) AND anterior AND (“OPEN” OR (“open” AND “bite”) OR “open bite”)
Sciences Direct	Orthodontic AND aligner AND open bite
Google Scholar	Orthodontic AND aligner AND open bite
Manual search	Orthodontic AND aligner AND open bite

2.3 Study Selection

The process of selecting studies was conducted independently and in duplicate. All pertinent articles were imported into Zotero, a bibliography generator. Initially, duplicate articles were eliminated. Subsequently, titles and abstracts were scrutinized for eligibility. Full-text reports were consulted for articles that appeared to meet the inclusion criteria. Ultimately, relevant articles were subject to comprehensive analysis.

2.4 Data Collection Process and Items

Data from the chosen articles for this study were extracted using a predefined standardized form by two independent reviewers. The collected information included author, year, details of participant, intervention,

outcomes, and author conclusions. In cases of doubt or disagreement between the two reviewers, resolution was achieved through discussion.

2.5 Risk of Bias of Individual Studies

The assessment of the risk of bias (RoB) in all pertinent studies utilized the Methodological Quality of Single Subject Finite Element Analysis (MQSSF) [3]. This tool is specifically crafted for the methodological evaluation of finite element studies.

It consists of 37 questions. A score of 1 is given for each "yes" response, and a score of 0 for each "no" response. The total score of the MQSSF will be calculated. Reliability is determined by the intra-class

correlation coefficient (ICC). An ICC greater than 0.75 indicates good and acceptable reliability.

3. RESULTS

3.1 Study Selection

The results of the electronic search and the subsequent article selection process were visualized in

the PRISMA flow diagram, aligning with PRISMA guidelines. Initially, 1266 studies were identified through both database and manual searches. Following the elimination of duplicates, 71 studies persisted, and only 26 advanced beyond the stage of title and abstract screening. Ultimately, 4 articles were included in the final selection, as depicted in the PRISMA flow diagram (Figure 1). All 4 studies were *in vitro* studies.

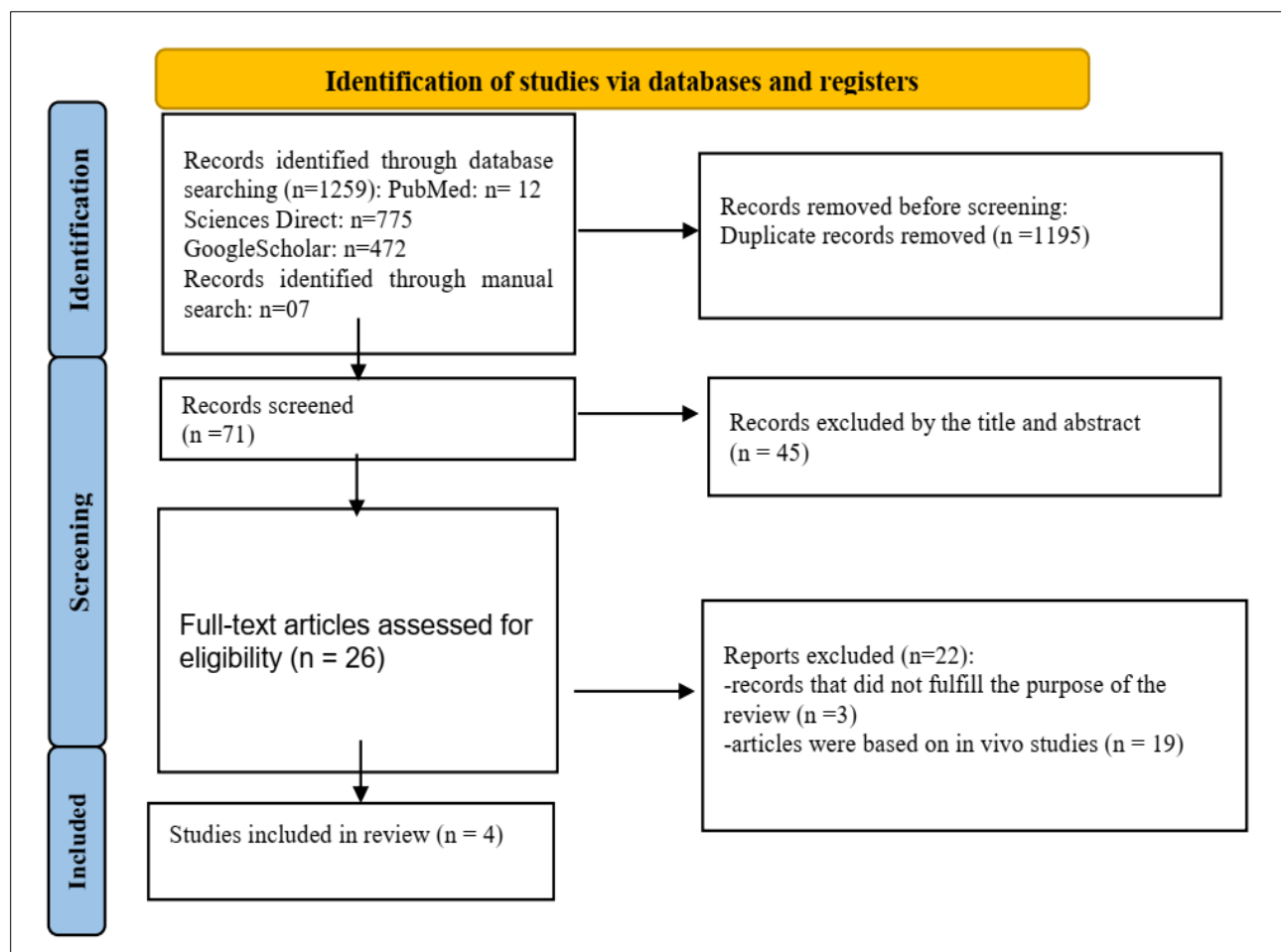


Fig. 1: Flow chart according to the PRISMA statement.

3.2 Study Characteristics

The research findings encompass four finite element studies. These four studies, conducted between 2019 and 2022, reflect a growing interest in the subject in recent years.

These studies specifically focused on two types of tooth movement: incisor extrusion and molar intrusion

The orthodontic appliance employed in these studies were clear aligners.

3.3 Data Extraction and Synthesis

The four articles included in this systematic review and the data extracted from each study are shown in Table 3.

Table 3 : Overview of included studies

Author	Year	Study Design	participant	Intervention	Outcomes	Conclusion
R. Savignano (4)	2019	Finite element study	A complete maxillary arch (14 teeth) was modeled by combining two different imaging techniques: cone beam computed tomography and structured light surface scanning. The geometries of the aligners and auxiliary elements were created using computer-aided design (CAD). The reconstructed digital models were imported into the Finite Element solver (Ansys® 17).	For extrusion, the authors compared the aligner without attachment with three models of aligners with auxiliaries: a palatal rectangular attachment, a buccal rectangular attachment, and a buccal ellipsoid attachment. This was done by simulating the movement using a workstation based on Intel Xeon. The FEA results were analyzed for each configuration by comparing the forces and moments delivered to the tooth.	-The extrusion of the maxillary central incisor is minimal when using the aligner without attachment (0.4N). -The palatal rectangular attachment showed the highest force along the extrusion axis (2N) with the least undesirable movements. -The presence of the attachment with the aligner is essential to make the extrusion movement possible.	-The extrusion of an upper central incisor cannot be achieved without any attachment. -The shape and position of the attachments affect the expected orthodontic movement. -In this case, the palatal rectangular attachment proved to be the best configuration to improve the efficiency of the aligner for the extrusion movement of a maxillary central incisor. -The position of the attachment, which influences the area of its active surface for the specific movement, showed a greater influence on the outcome than its shape.
Gabriele Rossini (5)	2021	Finite element study	For this study, a CAD model of a maxillary arch, designed based on the ideal proportions of the teeth, was used to create six models with different attachment configurations.	-The planned extrusion was 0.1 mm for the central and lateral incisors, performed simultaneously.-Six simulations were conducted: • Without attachments (NOATT); • With horizontal rectangular attachments only on the incisors (ATT1-2); • With rectangular attachments from the second molar to the canine (ATT3-7); • ATT3-7 + optimized extrusion attachments on the incisors (OTT); • ATT3-7 + horizontal rectangular buccal attachments on the incisors (RETT); • ATT3-7 + horizontal rectangular palatal attachments on the incisors (PALAT).-The following results were analyzed: • Tooth displacement pattern; • Aligner deformation; • Equivalent stress in the PDL; • Contact pressure between the aligner and the tooth surface.	-The tooth displacement pattern was found to be the same in all six configurations. -Planning for simultaneous extrusion of the upper anterior teeth resulted in lingual version of the central incisors, while the lateral incisors underwent buccal version. -The RETT and PALAT configurations showed better results in terms of the force system, with minimal deformation of the gingival part of the aligner.	-Aligners do not seem to be as effective in controlling the pure extrusion movements of the upper incisors. - From a clinical perspective, aligners could be indicated for treating patients with an open bite and buccally inclined upper incisors.

Author	Year	Study Design	participant	Intervention	Outcomes	Conclusion
Dian Fan (6)	2022	Finite element study	-CBCT images of a patient with extrusion of the maxillary second molar were selected to construct three-dimensional models of the maxilla, periodontal ligaments, dentition, and aligners.	-The models were divided into four groups based on the location of the attachment on the first molar: (1) no attachment (NA), (2) buccal attachment (BA), (3) palatal attachment (PA), and (4) buccal and palatal attachments (BPA). After applying an intrusion of 0.2 mm on the second molar, tooth displacements and stress distributions on the teeth, aligner, and periodontal ligament were analyzed using finite element software.	- The deformation of the entire aligner progressively decreased from the back to the front, with deformation decreasing as the number of attachments increased. - All groups showed the same movement pattern of the aligners. -Along the Z-axis, all points in the BPA group exhibited the greatest displacement, with mesial cusps displacing more (twice as much) than distal cusps. -BPA is the most effective for molar intrusion, BPA showed better stress distribution at the level of the periodontal ligament.	-This study showed that: -The position of the attachment affects the amount of molar intrusion, and it is essential for aligners to successfully achieve molar intrusion. -The combination of BA and PA showed the optimal intrusion effect and reduced uncontrolled buccal or lingual version. -The second molar shows an inevitable tendency to tilt mesially, regardless of the attachment position, and the result should be validated with more clinical cases.
Pratchawin Laohachairuon (7)	2022	Finite element study	-A 3D geometric model was prepared from a maxillary arch that included the maxilla, the periodontal ligament (PDL), the upper teeth with the right intruded central incisor, transparent aligners, and composite attachments. The maxilla and upper teeth were constructed from cone beam computed tomography (CBCT) data of a patient with an Angle class I skeletal relationship, well-aligned teeth, and normal tooth shape.	-Four models were created to simulate the extrusion of the maxillary central incisor: (1) without any attachment; (2) beveled rectangular attachment; (3) ellipsoidal attachment; and (4) horizontal rectangular attachment. The aligners were designed to achieve the extrusion of the upper central incisors. The constructed models were analyzed using the finite element method.	-The extrusion of the central incisor was observed in all models with attachments: the greatest amount of extrusion was with the horizontal rectangular attachment, followed by the ellipsoidal attachment, and finally the beveled rectangular attachment. - In the model without any attachment, there is very little extrusion of the incisor being attempted. - The maximum tensile stress was found around the apical area of the right upper central incisor. Maximum compressive stresses were observed around the apical area of the right upper lateral incisor and the left central incisor, as these teeth acted as anchors for the extrusion of the right upper central incisor. -Note: Palatal version of the incisor being extruded.	-The three attachment shapes: horizontal rectangular attachment, ellipsoidal attachment, and beveled rectangular attachment, can be used to achieve the extrusion of the upper central incisor. -The extrusion of the upper central incisor was induced by a force applied by the aligner at the cervical area of the attachment. -In all three models, the stress distribution in the PDL was found to be the same.

3.4 Risk of Bias in Included Studies

Using the "Methodological Quality Assessment of Single-Subject Finite Element Analysis Used in

Computational Orthopaedics" (MQSSF), all analyses are considered to have acceptable reliability.

Haut du formulaire

Bas du formulaire

Table 4 : RoB assessment of the included studies

	R. Savignano(4)	Dian Fan(6)	Gabriele Rossini (5)	Pratchawin Laohachaiaroon (7)
1	O	O	O	O
2	O	O	O	O
3	O	O	O	O
4	O	O	O	O
5	O	O	N	N
6	O	O	O	O
7	O	N	N	O
8	O	N	O	N
9	O	O	N	N
10	N	O	N	N
11	N	O	O	N
12	O	N	O	O
13	O	O	O	O
14	O	O	O	O
15	N	O	O	O
16	O	O	N	O
17	N	O	O	O
18	O	O	O	O
19	O	O	O	O
20	N	N	N	O
21	N	N	O	N
22	N	O	N	N
23	O	O	O	N
24	O	O	O	O
25	O	O	O	N
26	O	O	O	O
27	O	O	N	N
28	O	N	O	O
29	O	O	O	N
30	O	O	O	O
31	O	O	O	N
32	O	N	O	O
33	N	O	O	O
34	N	O	N	N
35	O	N	O	O
36	O	O	N	O
37	N	O	N	O
Score	27	29	26	24

3.5 Certainly Assessment

The level of scientific evidence of each of the included studies was determined using the criteria established by the Oxford Center for Evidence-based Medicine, as shown in Table 6. The four articles were deemed to be of evidence level B. Consequently, conclusions of a moderate level of evidence could be drawn from the review process. This suggests a moderate level of confidence in the results and conclusions derived from the review process.

Table 6: level of scientific evidence

Reference	Level of evidence	Grade of recommendation
(4)	2c	B
(6)	2c	B
(5)	2c	B
(7)	2c	B

4. DISCUSSION

4.1 Summary of Evidence

Up until 2009, according to a prospective study conducted by Kravitz *et al.*, [8], evaluating the accuracy of dental movements with aligners, extrusion was the least precise dental movement with aligners, achieving only 29.6% of the planned movement. Specifically, the extrusion of the maxillary central incisor proved to be the most challenging (18.3%), followed closely by the mandibular central incisor (24.5%). On average, extrusion measured 0.56 mm.

They explained that the difficulty of this movement was likely due to the aligner's inability to fully encompass the tooth during vertical traction. On the contrary, Boyd [9], reported that absolute extrusion is always challenging even with attachments. He advocates for extruding the teeth using elastics from buttons attached to the vestibular surfaces of the teeth and

combining extrusion with movements more easily achieved with aligners, such as lingual version.

Indeed, there should be sufficient space next to the tooth to be moved to allow for its extrusion [10, 11]. This can be achieved through interproximal enamel reduction [12]. Attempting extrusion with insufficient space next to the tooth may lead to iatrogenic intrusion. Furthermore, this additional space increases the contact surface between the tooth and the aligner [13, 14].

A series of studies was conducted to investigate the predictability of aligners in extrusion of anterior teeth or intrusion of posterior teeth.

Three finite element analyses studied the extrusion of maxillary incisors with aligners. According to the findings of a study by Savignano *et al.*, [4], it was demonstrated that the palatal rectangular attachment was the most effective configuration for enhancing the efficacy of aligners in the extrusion of a maxillary central incisor. Moreover, the position of the attachments appears to have a more significant impact on dental movement than their shape. In other words, even if attachments of the same shape are placed at the same position, they all generate the same amount of extrusion force.

Therefore, it is recommended to use aligners with attachments that have a flat active surface on which the force can be applied. These results are consistent with those of a study by Rossini *et al.*, [5], which showed that the RETT (buccal rectangular horizontal attachments on the incisors) and PALAT (palatal rectangular horizontal attachments on the incisors) configurations provided better results in terms of force distribution across the aligner while minimizing deformation of the gingival part of the aligner.

Only one finite element analysis studying molar intrusion with aligners was included in our review. In 2022, a study conducted by Dian Fan *et al.*, [6], examined the biomechanical implications of attachment position in the process of maxillary molar intrusion using aligners. Their research demonstrated that the use of attachments was crucial for successfully achieving this movement. Additionally, they found that the specific location of the attachment had a significant impact on the amount of molar intrusion. The results of this study indicated that the combination of buccal (BA) and palatal (PA) attachments offered the most optimal intrusion effect, reducing uncontrolled buccal-lingual inclinations.

However, it is important to note that the second molar had a tendency to tilt mesially, regardless of the attachment position.

4.2 Limitations

Our systematic review noted that most studies had a moderate level of evidence. The main sources of

bias identified were related to the design of included studies, which were finite element studies.

Additionally, our article selection was limited to studies available online and accessible for free, as well as those published or translated into English. This approach might have excluded relevant scientific studies published in other languages, posing a selection bias.

5. CONCLUSION

In conclusion, The use of attachments has proven crucial for successfully achieving vertical movements with aligners. In particular, the palatal horizontal rectangular attachment with a flat active surface has been shown to be the most effective configuration for enhancing the extrusion movement of incisors.

Regarding molar intrusion, the combination of buccal and palatal attachments provides the most optimal intrusion effect by reducing uncontrolled buccal-lingual inclinations.

Declarations Section:

Ethics Approval and Consent to Participate: Not applicable

Consent for Publication: Not applicable

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Authors' Contributions:

DI: study conception and design

TR: data collection

RR: analysis and interpretation of results

AF and AW: draft manuscript preparation

TS and AA: revised the text

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