

Effectiveness of maxillary arch expansion using clear aligners in adult patients: a systematic review and meta-analysis

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Introduction: Invisalign, introduced by Align Technology, Inc. in 1997, is a system of clear plastic aligners that provides aesthetic orthodontic treatment plus treatment customisation. Created using impressions or intraoral digital scans, patients wear and sequentially exchange removable, 0.75 mm thick polyurethane appliances. The aligners improve smile appearance, correct dentoalveolar posterior crossbites, increase arch length, relieve crowding, and provide more space for tooth alignment. Dentoalveolar expansion is a preferred alternative to interproximal tooth reduction when treating a patient using the Invisalign clear appliance.

Materials and methods: The present review systematically searched electronic databases for prospective and retrospective studies on dentoalveolar expansion using clear aligner therapy in human subjects. The quality of the studies was assessed using the revised Cochrane risk of bias tool.

Results: A high risk of bias was noted in the systematic evaluation of five human trials comprising 254 healthy individuals. The most frequent cause of bias was found to be patient selection. Patient attrition was caused by age-related issues, inadequate compliance, and the lack of blinded outcome evaluation, underscoring the need for better research protocols.

Conclusion: The present study examined maxillary arch expansion in adult patients who received clear aligner therapy. It was found that the efficiency of expansion at the completion of an aligner treatment sequence may be marginally better than at the completion of an expansion treatment due to the hysteresis (the difference between the predicted and actual results of expansion) of Invisalign appliances, which enhances effectiveness and generates the greatest expansion in the first and second premolar region.

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Introduction

The demand for aesthetically acceptable alternatives to traditional fixed orthodontic appliances has increased, as more adult patients seek treatment.¹ Kesling's positioner, described in 1945, was a precursor to aligner therapy, and subsequently thermoformed splints in the form of retainers have been used to subtly correct the positions of teeth.² Since the thermoformed splints required significant manufacturing effort and resulted in limited tooth movement, Sheridan expanded the application of vacuum-formed aligners made on casts by removing and grinding portions of the working model, creating windows, deforming the material with specific pliers, arranging composite attachments on the teeth, and adding elastic traction to attachments.² Subsequently, in 1997, Align Technology, Inc. (Santa Clara, CA, USA) introduced Invisalign®, which applies a sequence of plastic aligners to move teeth following customisation and mass-production to produce personalised appliances.³ Invisalign uses 0.75 mm-thick polyurethane material to manufacture aligners that are worn for one to two weeks before replacement by the next appliance in the series.⁴ Custom aligners are made using stereolithographic technology from intraoral digital images obtained by scanning in the dental office or, alternatively, from an impression. Maintaining patient compliance is essential for optimal results as patients are required to wear their aligners for at least 22 hr daily.

The expansion of a constricted arch can alleviate crowding, increase the arch length, provide more space for alignment, relieve dentoalveolar posterior crossbites, or enhance a smile's transverse dimension.⁵ Using clear aligners, dentoalveolar expansion is a potential alternative to interproximal tooth reduction^{6,7} although studies on the effectiveness of aligners used for arch expansion are few. The current review aims to identify the best available scientific data on the efficacy of arch expansion by using the Invisalign appliance through a systematic search of the literature.

Materials and methods

Protocol and registration

The present systematic review was registered at the National Institute for Health Research Prospero International Prospective Register of Systematic

Reviews (Registration number: CRD42023475837). The research protocol was designed according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) guidelines of 2020.

Eligibility criteria

A) Inclusion Criteria:

- 1) Participants: Adult patients in the permanent dentition.
- 2) Intervention: Dentoalveolar expansion using clear aligner therapy.
- 3) Comparison: Studies evaluating arch width changes before and after clear aligner treatment.
- 4) Outcome:
 - i) Primary outcome: Efficiency of arch expansion.
 - ii) Secondary outcome: Accuracy and Predictability of maxillary arch expansion.
- 5) Study design: Prospective and retrospective studies in the English language.

B) Exclusion Criteria: In vitro studies, animal studies, case reports, review articles, opinion articles, and letters to editors.

Information Sources, Search Strategy, and Selection Process

A comprehensive search was conducted using electronic databases and supplemented by a manual search, to identify all relevant studies associated with arch expansion as a result of clear aligner therapy. Three electronic databases: PubMed, Google Scholar, and the Cochrane library were searched using the key words "(clear aligner OR permanent dentition) AND (maxillary arch expansion) AND (arch width changes) AND (efficiency OR predictability of maxillary arch expansion)". A hand search of prominent orthodontic journals was also undertaken while unpublished literature was searched on ClinicalTrials.gov.in. In addition, the reference lists of relevant studies, meta-analyses, systematic reviews, and other review articles were screened for potential inclusion.

Search strategy

The search strategy was developed using relevant Medical Subject Headings (MeSH) terms, keywords, and Boolean operators "AND" and "OR" combinations. The following search terms and their

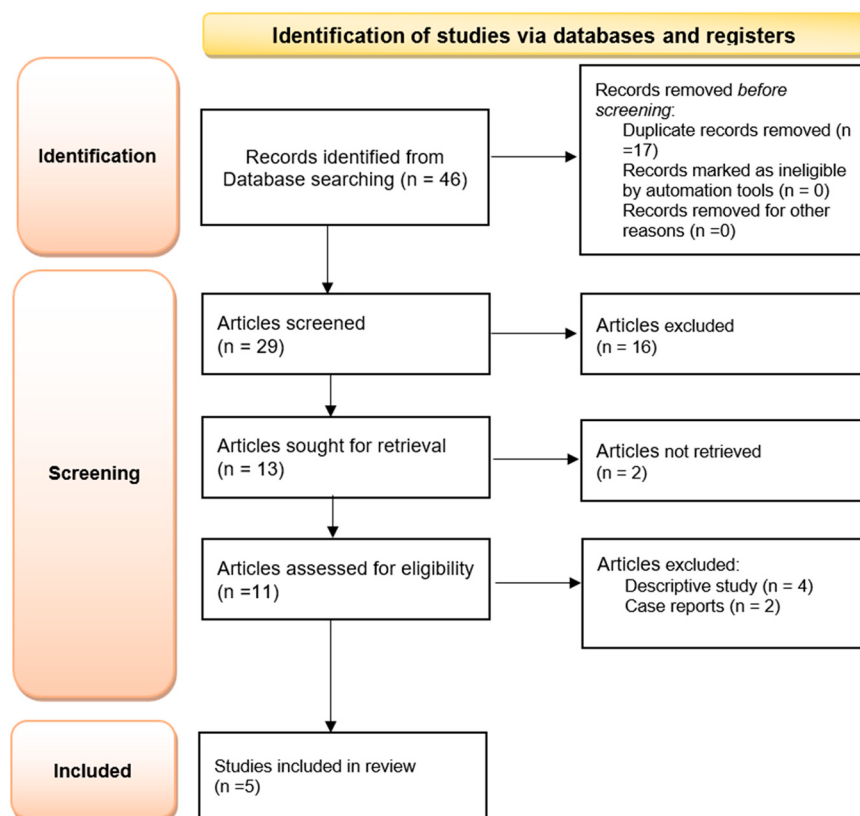


Figure 1. Prisma flow diagram of study selection.

combinations were applied in the search strategy: “(clear aligner OR maxillary arch expansion OR Invisalign) AND (OR efficacy OR predictability of maxillary arch expansion)” The search strategy was adapted to the specific syntax and subject headings of each electronic database.

Selection process

The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Two reviewers independently screened the titles and abstracts for all relevant articles to determine their eligibility for inclusion. Full-text articles of potentially eligible studies were assessed independently by the two reviewers. Any discrepancies between the reviewers were resolved through discussion or consultation with a third reviewer.

Data collection process and data items

Following the identification of relevant studies, data were extracted using a pre-designed data recording

form. The items extracted included the study design, the name of the author, the year of publication, age and gender of the participants, the description of the participants and grouping, the type, and frequency of the intervention, diagnostic methods, observation, and outcomes.

Assessment of risk of bias in a non-RCT study

A risk of bias assessment for a non-RCT study was conducted using the ROBINS-I tool and following the recommended approach. The two-part tool was used to address the seven specific bias domains due to confounding, the bias of participant selection, the bias of intervention classification, the bias due to deviations from intended interventions, the bias due to missing data, the bias in the measurement of outcomes, and the bias in the selection of the reported result. The signalling questions were broadly factual in nature and aimed to facilitate judgements about the risk of bias. The categories for the risk of bias judgements were “Low risk”, “Moderate risk”, “Serious risk” and “Critical risk” of bias.

Table 1. Demographic details

Sr. No.	Study ID	Study design	Objectives	Number of patients/sex	Mean age
1.	Jean-Phillippe Houle et al. June, 2017 Angle Orthodontist.	Retrospective study	To investigate the predictability of arch expansion using Invisalign	N = 64 Male = 23 Female = 41	Mean = 31.2 years Range = 18-61 years
2.	Zhou and Guo August, 2020	Prospective study	To quantify the efficiency of arch expansion using the Invisalign system in patients, To investigate the movement patterns by comparing actual expansion outcomes of crown and root with virtual planned expansion in ClinCheck software, To ascertain whether the preset expansion amount and initial molar torque correlated with the efficiency of bodily expansion movement.	N = 20 Male = 5 Female = 15 (Chinese adults)	Mean = 28.5 ± 6.3 years Range = 20-45 years
3.	Ignacio Morales-Burruezo et al. December, 2020 PLOS ONE	Retrospective study	To determine the efficacy of the Invisalign system for arch expansion, and to assess the predictability of the measurements planned by Clincheck software for the use of the transparent aligners at the end of the first treatment phase	N = 114	Range = 18-75 years
4.	Roberta Lione et al. February, 2021 Angle Orthodontist	Prospective study	To evaluate tooth movements during maxillary arch expansion with clear aligner treatment	N = 28 Male = 12 Female = 16	Mean = 31.9 ± 5.4 years
5.	Gabriella Galluccio et al. March, 2023 International Journal of Environmental Research and Public Health	Prospective study	To evaluate the efficacy and accuracy of maxillary arch transverse expansion using the Invisalign clear aligner system without auxiliaries other than Invisalign attachments.	N = 28	Mean = 17 ± 3.2 years Range = 13-25 years

Results

Study selection

The electronic screening of PubMed and Google Scholar identified 46 articles. After adjusting for

duplicates, 29 articles were assessed for inclusion in the present study. The majority were later excluded because of irrelevant titles or abstracts, leaving 11 articles. After excluding four descriptive studies and two case reports, 5 original articles remained for

analysis. The PRISMA flowchart of the electronic database search is presented in Figure 1.

Study characteristics

Participant selection

Five human studies involving a total population of 254 healthy participants were assessed. Of the five studies, three were prospective and two were retrospective in nature. The demographic details of all of the participants are shown in Table I. Table II lists the parameters examined in each study, as well as the records gathered, and the techniques of collection applied in the data analysis. The results and corresponding conclusions from each study are displayed in Table III.

RoB of the studies

The risk of bias assessment for non-RCT studies is summarised in Table IV. There was a significant risk of bias in every reviewed study, with patient selection and the lack of a blinded assessment being the most frequent sources. None of the trials addressed the result of the assessor's blinding. A significant risk of bias was indicated by two investigations (Houle et al. and Morales-Burruezo)^{6,7} because of the wide age range of the patients. Poor compliance was cited as a reason for patient attrition in a study by Lione et al.,⁸ thereby indicating a significant risk of bias (Figure 2).

Results of the meta-analysis

Comparison of change in the inter-canine width before and after aligner treatment (Figure 3).

A meta-analysis was performed on three studies that qualified and provided the required data outcome for a quantitative analysis depicted as a forest plot. Because heterogeneity was more than 50% ($I^2 = 0\%$) following the conducted meta-analysis, a fixed effect model was applied. The change in inter-canine width after aligner treatment was greater than the inter-canine width before treatment (SMD: -0.80; 95% CI = -1.02 to -0.58; Z value = 7.06), and the difference was statistically significant ($p < 0.00001$).

Comparison of the inter-first premolar width before and after aligner treatment (Figure 4).

A meta-analysis was performed on three studies that qualified with the required dataset that could be quantitatively analysed and depicted as a forest plot. Heterogeneity was more than 50% ($I^2 = 0\%$) and so a fixed effect model was applied. The change in inter-first premolar width after the orthodontic treatment was greater than the inter-first premolar width before treatment (SMD: -1.13; 95% CI = -1.36 to -0.90; Z value = 9.62), and the difference was statistically significant ($p < 0.00001$).

Comparison of the inter-second premolar width before and after aligner treatment (Figure 5).

A meta-analysis was performed on three studies that contained the required data that could be quantitatively analysed and depicted as a forest plot. Heterogeneity was more than 50% ($I^2 = 0\%$) and so a fixed effect model was applied. The change in inter-second premolar width after the aligner treatment was greater than the inter-second premolar width before treatment (SMD: -1.07; 95% CI = -1.30 to -0.84; Z value = 9.18), and the difference was statistically significant ($p < 0.00001$).

Comparison of the inter-molar width before and after aligner treatment (Figure 6).

A meta-analysis was performed on four comparisons from three studies that contained the required dataset for quantitative analysis and depicted as a forest plot. Heterogeneity was more than 50% ($I^2 = 0\%$) and so a fixed effect model was applied. The change in inter-molar width after the aligner treatment was greater than the inter-molar width before treatment (SMD: -0.72; 95% CI = -0.93 to -0.52; Z value = 6.69), and the difference was statistically significant ($p < 0.00001$).

Comparison of the change in inter-canine width after aligner treatment with the change predicted by the ClinCheck software (Figure 7).

A meta-analysis was performed on five studies that provided the required dataset for quantitative analysis and depicted as a forest plot. Heterogeneity was more than 50% ($I^2 = 71\%$) and so a random effect model was applied. The change in inter-canine width after aligner treatment was lower than that predicted by the ClinCheck software (SMD: 0.57; 95% CI = 0.20 to 0.93; Z value = 3.06), and the difference was statistically significant ($p = 0.002$).

Table II. Data analysis

Sr. No.	Study ID	Groups	Data Collection	Records taken	Parameters measured	Additional parameters
1.	Jean-Phillippe Houle et al. June, 2017 Angle Orthodontist.		1) Pre-treatment digital models created from an iTero scan. 2) Post-treatment digital models created from an iTero scan. 3) Digital models from Clincheck obtained from Align Technology to measure planning accuracy.	Interdental width of both arches 1) Canine tip 2) Canine gingival 3) First premolar tip 4) First premolar gingival 5) Second premolar tip 6) Second premolar gingival 7) First molar tip 8) First molar gingival	(For both arches) 1) Mean of planned transverse changes 2) Mean difference between the amount of change planned and final outcome	
2.	Zhou and Guo August, 2020	According to unilateral expansion for each first molar- 1) Group A ($n = 14$); Expansion ≤ 1 mm 2) Group B ($n=20$); Expansion 1-2 mm 3) Group C ($n = 6$); Expansion 2 mm According to baseline torque by root vector analysis by Dolphin software 4) Group D ($n = 11$); faciolingual inclination -2° 5) Group E ($n = 16$); faciolingual inclination -2° to 2° 6) Group F ($n = 13$); faciolingual inclination $\geq 2^\circ$ to $<6^\circ$	Pre-expansion (T0) and post-expansion (immediately after finishing N+2 aligner) (T1) records collected, consisting of the following: 1) Digital models from stereolithography (.stl) files created from plaster models converted from polyvinyl siloxane (PVS) impressions by Optimics scanner (Activity 880, Smart Optics, Germany). 2) T0 digital dentition models in ClinCheck provided as .stl files from Align Technology (Santa Clara, CA, USA). 3) Conebeam computed tomography (CBCT) records as digital imaging and communications in medicine (DICOM) files, taken by GALILEOS Viewer (Sirona, Germany), in the participant's natural head position (NHP)	Interdental width of maxillary arches 1) Canine 2) First premolar 3) Second premolar 4) First molar	For maxillary arch 1) Expansion efficiency for crown 2) Efficiency of bodily expansion movement	—

Table II. Data analysis

Sr. No.	Study ID	Groups	Data Collection	Records taken	Parameters measured	Additional parameters
3.	Ignacio Morales-Burruezo et al. December, 2020 PLOS ONE	According to degree of complexity of transverse malocclusion- 1) 1 Tooth in crossbite (16.7%) 2) 2 Teeth in crossbite (10.5%) 3) >3 Teeth in crossbite (8.8%) 4) Bilateral crossbite (9.6%) 5) No crossbite (44.7%) 6) Second molar crossbite (9.6%)	1) Diagnostic records obtained using Itero intraoral scanner, at the start and end of first phase of treatment 2) Clincheck registers analyzed at 3 stages a) Dimensions recorded at start of first treatment phase (T1) b) Dimensions generated by Clincheck software as predicted measurements at end of first treatment phase (T2) c) the real dimensions obtained the start of the second treatment phase (also known as "first additional aligners") (T3) 3) Occlusal images of the maxilla at three stages (T1, T2 and T3) 4) Images were exported to a program (Keynote) designed to measure angulation- a) Measuring widths b) Measuring the rotation of the first molar c) Measuring molar inclination	Measurements were taken from occlusal images captured at T1, T2, and T3- 1) Measuring widths (vestibular (buccal) cusps of canine, first and second premolars, and mesio-vestibular cusps of first and second molars) 2) Measuring the rotation of the first molar (the angle formed by tracing a line from the disto-vestibular to mesio-palatal cusp of the first molars to the perpendicular line that passes through the point of contact of the central incisors and the horizontal line traced from the tip of the mesio-vestibular cusp of both first molars) 3) Measuring molar inclination (the tangent to the vestibular faces of the first molars)	1) Treatment efficacy (differences between means at T3 and T1) 2) Predictability (differences between means at T2 and T3).	

Table II. Data analysis

Sr. No.	Study ID	Groups	Data Collection	Records taken	Parameters measured	Additional parameters
4.	Roberta Lione et al. February, 2021 Angle Orthodontist		1) Pretreatment (T1) digital models (.stl files), created from an iTero scan, were collected 2) Posttreatment (T2) digital models (.stl files), created from an iTero scan, were collected 3) The final position of the ClinCheck representation was collected to establish the predictability of the final virtual model (T2 ClinCheck)	A) The following transverse linear values were measured only on the upper arch for each T1 and T2 model and the T2 ClinCheck model- 1) Inter canine width (A) 2) First premolar width (B) 3) Second premolar width (C) 4) Mesial first molar (D) 5) Distal first molar width (E) 6) Mesial second molar width (F) 7) Distal second molar width (G) 8) Transpalatal first molar width (H) 9) Transpalatal second molar width (I) B) Angular measurements (inclinations) determined using digital models at T1 and T2 and T2 ClinCheck models a) Upper canine b) Premolar c) First molar d) Second molar	—	—

Table II. Data analysis

Sr. No.	Study ID	Groups	Data Collection	Records taken	Parameters measured	Additional parameters
5.	Gabriella Galluccio et al. March, 2023 International Journal of Environmental Research and Public Health		An intraoral scan were performed with the Itero Flex® scanner and final position of ClinCheck® representation (TC) collected. Models collected were- 1) Pretreatment STL model (T0) of maxillary arch before starting Invisalign treatment. 2) Post-treatment STL model (T1) of maxillary arch at the end of the treatment with Invisalign 3) STL model from the final model programmed on the ClinCheck® software (TC)	The following transverse linear measurements were carried out on the upper arch for each T0 and T1 model and for the ClinCheck® model (TC) 1) Inter canine cusp width (A) 2) Inter canine gingival width (B) 3) First inter-premolar width (C) 4) Second inter-premolar width (D) 5) First molar mesio-vestibular (buccal) cusp width (E) 6) First molar gingival width (F)	1) Expansion obtained was calculated by the difference between the post-treatment distance with respect to the pretreatment amplitude (T1-T0). 2) Planned expansion was calculated by the difference between the planned distance on the Clincheck with respect to the pretreatment amplitude (TC-T0). 3) Accuracy of expansion was calculated by the difference between planned expansion on the Clincheck with respect to the obtained expansion (TC-T1).	Clinical accuracy (%) was achieved for all measurements, using the equation [(expansion obtained/ planned expansion) × 100].

Table III. Outcome

Sr. No.	Study ID	Outcome	Conclusion
1.	Jean-Phillippe Houle et al. June, 2017 Angle Orthodontist.	1) For every maxillary measurement, there was a statistically significant difference between Clincheck and the final outcome. 2) The most reliable area to predict transverse changes in the maxilla was the canine cusp tip with 88.9% of the change achieved, a mean difference of 0.22 ± 0.74 mm. 3) For every lower arch measurement, at the gingival margin, there was a statistically significant difference between the Clincheck plan and the final outcome 4) Measurements at the cusp tips in the lower arch showed non-statistically significant differences between Clincheck and the final outcome. 5) Variance was not equal for any of the measurements done either upper or lower, meaning that the amount of change planned was not associated with prediction error. 6) All of the <i>P</i> values were recorded as significant for the variance ratio tests	1) The mean accuracy for the maxilla is 72.8% a) 82.9% at the cusp tips b) 62.7% at the gingival margins 2) Invisalign becomes less accurate going from anterior to posterior region. 3) The lower arch presented an overall accuracy of 87.7% a) 98.9% for the cusp tips b) 76.4% for the gingival margins. 4) All cusp tip post-treatment measurements were found to have a non-statistically significant difference when compared with Clincheck. 5) Clincheck prediction of expansion involves more bodily movement of the teeth than can be seen clinically. 6) But actually more dental tipping was observed.
2.	Zhou and Guo August, 2020	1) There was no significant difference ($P > 0.05$) in the transverse dimension variables between the T0 ClinCheck and digital models. 2) There was a significant difference ($P > 0.05$) between the amount of designed expansion and amount of achieved expansion for the canine, first premolar, second premolar, and first molar 3) The effect of skeletal arch expansion in CBCT a) No significant change ($P > 0.05$) was observed in maxillary basal bone width b) The buccal alveolar crest width (BACW) increased significantly by 0.87 mm ($P > 0.05$) c) The lingual alveolar crest width (LACW) increased significantly by 0.75 mm ($P > 0.05$) d) The maxillary alveolar bone width at the level of the most convex point of the buccal alveolar ridge crest (BCPW) showed no significant difference between T0 and T1 ($P > 0.05$) e) The buccolingual inclination of the maxillary molar (HLA) significantly increased by 2.07 after arch expansion	1) The Invisalign system can increase arch width by tipping movement of posterior teeth. 2) The efficiency of bodily buccal expansion for maxillary first molars averaged 36.35%. 3) The preset amount of expansion movement and initial torque are negative correlated with bodily expansion efficiency.

Table III. Outcome

Sr. No.	Study ID	Outcome	Conclusion
3.	Ignacio Morales-Burruezo et al. December, 2020 PLOS ONE	1) Differences between T3 and T1 indicated changes resulting from treatment in the first sequence of transparent aligners. a) Widths underwent significant advances as a result of treatment b) Maximum expansion was obtained at the pre-molar level, exceeding 8% c) Width at the second molar underwent a smaller expansion (+0.54%) d) For Inclinations and rotations, the increase in inclination was significant in every case, and variations in rotation were of around 2% 2) Differences between T3 and T1 analyzed by subgroups (no crossbite group and crossbite group) a) The only significant differences between the two groups were in inclination of the right and left first molars, and rotation of left first molar. b) For all other variables expansion obtained the same efficacy regardless of group 3) Differences between T2 and T3 indicated the precision of Clincheck virtual planning a) For all widths, virtual planning obtained prognoses of greater expansion than those actually achieved b) All the plan's estimations, with the exception of the second molar ($p = 0.183$), were significantly higher than the actual outcomes. c) Regarding inclinations, virtual planning was less optimistic for first and second molars, obtaining higher values at T3 than those planned virtually, with significant difference for the upper left first molar. d) For rotations, planning overestimated the value obtained at the upper right first molar 4) Differences between T2 and T1 analyzed by subgroups (no crossbite group and crossbite group). No significant differences were observed between the two groups.	1) Aligners are an effective tool for producing arch expansion, being more effective in premolar area and less effective in canine and second molar area. 2) Predictability was reasonable for expansion movement. 3) Based on these results, overcorrection should be considered at the virtual planning stage in order to obtain the expected outcomes.

Table III. Outcome

Sr. No.	Study ID	Outcome	Conclusion
4.	Roberta Lione et al. February, 2021 Angle Orthodontist	1) For every maxillary measurement, there was a statistically significant difference between pretreatment values and final outcomes, except for measurements at the second upper molars. 2) A decreasing expansion gradient was observed moving from the anterior to posterior part of the arch. 3) The comparison of T2-T1 angular outcomes showed statistically significant changes in the inclinations of all teeth except for the second permanent molars. 4) The predictability of ClinCheck of the Invisalign software was determined after completion of treatment a) For linear measurements, statistically significant differences were detected only for the intercanine width. b) Regarding the angular variables, the canine inclinations showed low predictability between the changes predicted by ClinCheck and the changes observed after the completion of treatment. The amount of change planned was not associated with the obtained outcome.	1) The development of the maxillary arch showed a progressive reduction in the expansion rate in the canine, premolar, and posterior regions, with the greatest net increase at the first and second premolars. 2) The Invisalign system can increase arch width by increasing the buccal tipping of maxillary teeth. 3) Buccal tipping followed the same decreasing gradient from anterior to posterior that was observed for transverse width changes. 4) The Invisalign system showed poor predictability between the virtual recreation by ClinCheck and observed treatment outcomes for the maxillary canines. 5) An overcorrection of upper canine movements should be planned during dentoalveolar expansion.

Table III. Outcome

Sr. No.	Study ID	Outcome	Conclusion
5.	Gabriella Galluccio et al. March, 2023 International Journal of Environmental Research and Public Health	1) The planned expansion (mm) increased progressively from anterior to posterior at the level of the cusps. 2) The planned expansions in millimeters for intercanine and intermolar gingival width were less than those for the cusp width. 3) The intercanine, inter-premolar, and intermolar measurements at the level of the cusps, the differences between the expansion obtained and the planned expansion were not statistically significant, while they were statistically significant for gingival measurements. 4) There is more vestibular tipping movement than body movement of the crowns at the level of the canine and of first molars.	1) The efficacy in maxillary arch transverse expansion, on average, is rated at 70%, and is not related to the type of tooth considered but applies overall. 2) Effectiveness is lower at the lingual level, with an average of 55% at the intermolar level, and 46% at the canine level. 3) Statistically significant differences were found between the efficacy at the cuspal level compared to the efficacy measured at the most apical point of the palatal surface of the tooth, indicating that there is more tipping movement than body movement. 4) The ClinCheck programs a body movement, whereas what we have obtained is a tipping movement

Comparison of the change in inter-first premolar width after aligner treatment with the change predicted by the ClinCheck software (Figure 8).

A meta-analysis was performed on five studies that provided the required dataset for quantitative analysis and depicted as a forest plot. Heterogeneity

Table IV. Assessment of risk of bias in included studies (Non-RCT)

Study	Pre-intervention		Intervention		Post-intervention			
	Risk of bias of confounding	Risk of bias in the selection of participants	Risk of bias in the intervention classification	Risk of bias as a result of deviation from planned intervention	Risk of bias as a result of missing data	Risk of bias in the measurement of results	Risk of bias in the selection of reported results	General Judgment of Risk of Bias
Houle et al 2017	Low	Serious	Low	Low	Low	Serious	Low	Serious
Zhou and Gou 2020	Low	Moderate	Low	Low	Low	Serious	Low	Serious
Morales-Burruezo et al 2020	Low	Serious	Low	Low	Low	Serious	Low	Serious
Lione et al 2021	Low	Low	Low	Low	Serious	Serious	Low	Serious
Galluccio et al 2023	Low	Low	Low	Low	Low	Serious	Low	Serious

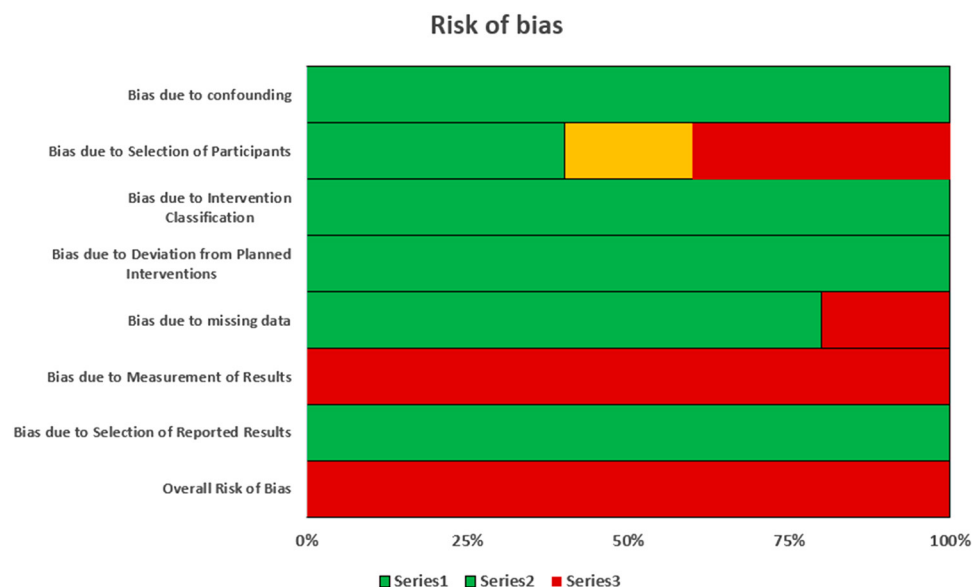


Figure 2. Risk of bias graph for the included studies.

was more than 50% (I2 = 90%) and so a random effect model was applied. The change in inter-first premolar width after orthodontic treatment was

lower than that predicted by the ClinCheck software (SMD: 0.57; 95% CI = -0.06 to 1.20; Z value = 1.78)

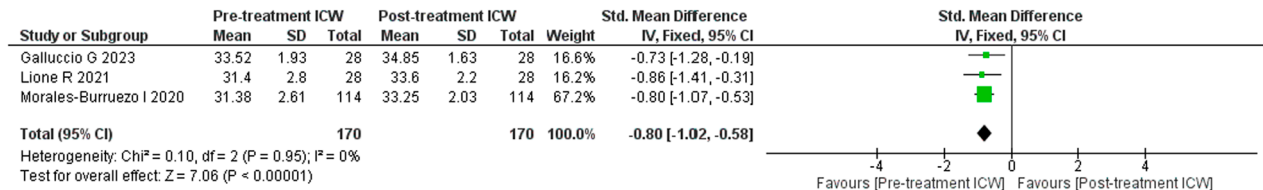


Figure 3. Comparison of the change in inter-canine width before and after orthodontic treatment.

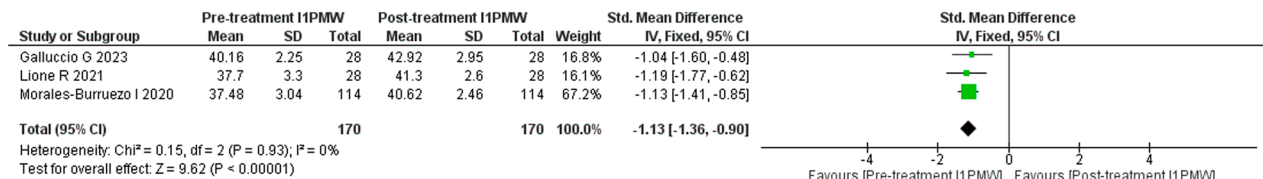


Figure 4. Comparison of the inter-first premolar width before and after orthodontic treatment.

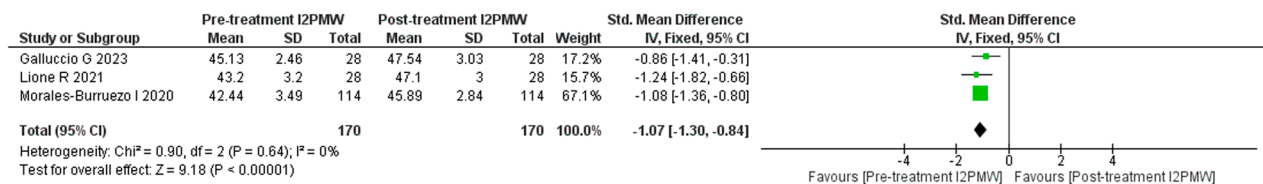


Figure 5. Comparison of the inter-second premolar width before and after orthodontic treatment.

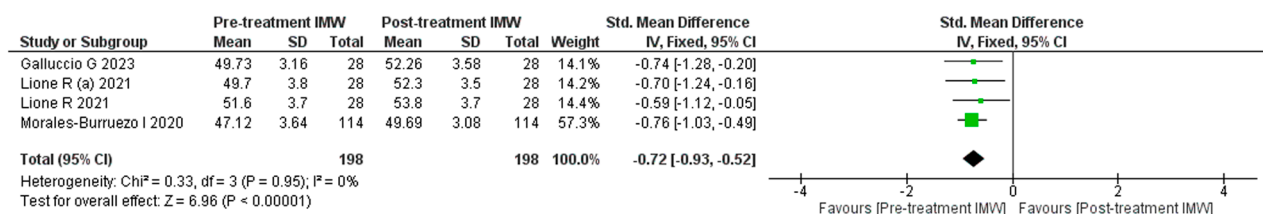


Figure 6. Comparison of the inter-molar width before and after orthodontic treatment.

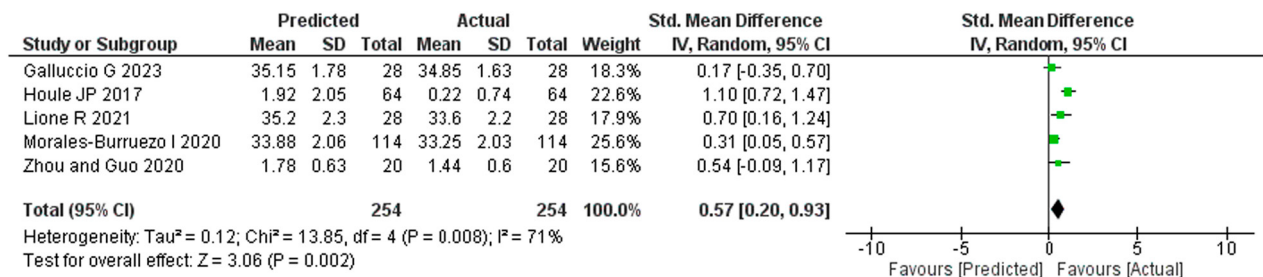


Figure 7. Comparison of the change in intercanine width after orthodontic treatment with the change predicted by the ClinCheck software.

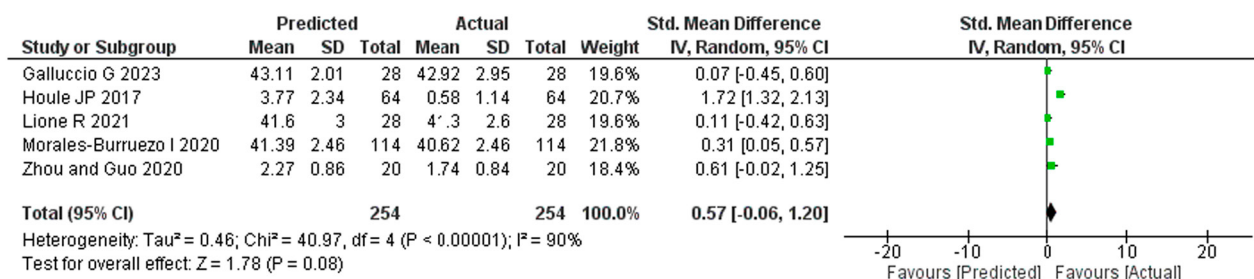


Figure 8. Comparison of the change in inter-first premolar width after orthodontic treatment with the change predicted by the ClinCheck software.

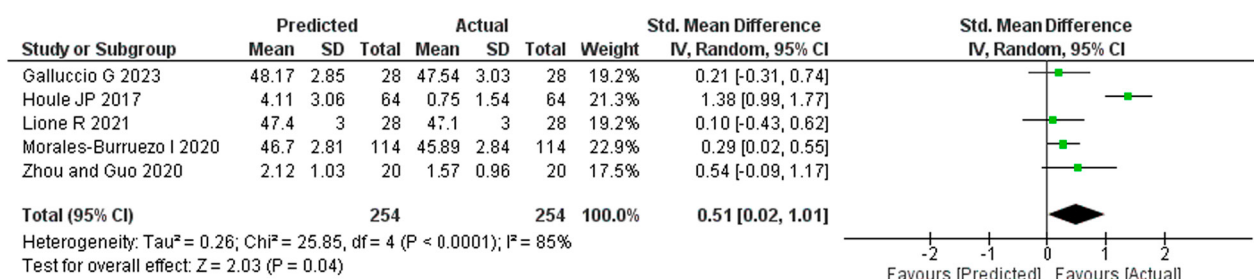


Figure 9. Comparison of the change in intersecond premolar width after orthodontic treatment with the change predicted by the ClinCheck software.

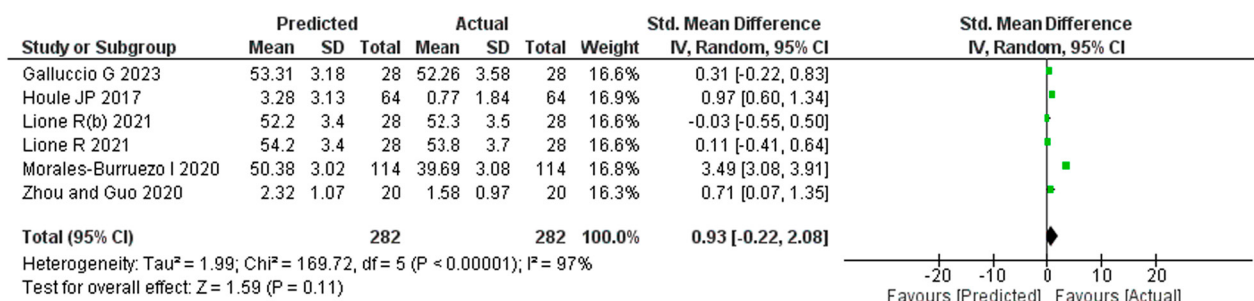


Figure 10. Comparison of the change in inter molar width after orthodontic treatment with the change predicted by the ClinCheck software.

but the difference was statistically non-significant ($p = 0.008$).

Comparison of the change in inter-second premolar width after aligner treatment with the change predicted by the ClinCheck software (Figure 9).

A meta-analysis was performed on five studies that provided the required dataset for quantitative analysis and depicted as a forest plot. Heterogeneity was more than 50% ($I^2 = 85\%$) and so a random effect model was applied. The change in inter-second premolar width after orthodontic treatment was lower than that predicted by the ClinCheck software (SMD: 0.51; 95% CI = 0.02 to 1.01; Z

value = 2.03) and the difference was statistically significant ($p = 0.04$).

Comparison of the change in intermolar width after aligner treatment with the change predicted by the ClinCheck software (Figure 10).

A meta-analysis was performed on five studies that provided the required dataset for quantitative analysis and depicted as a forest plot. Heterogeneity was more than 50% ($I^2 = 97\%$) and so a random effect model was applied. The change in intermolar width after orthodontic treatment was lower than that predicted by the ClinCheck software (SMD: 0.93; 95% CI = -0.22 to 2.08; Z value = 1.59),

but the difference was statistically non-significant ($p = 0.11$).

Discussion

The present systematic review summarises evidence from prospective and retrospective studies which evaluated the effectiveness of maxillary arch expansion by clear aligners in adult patients. Invisalign aligners have been shown to be effective in treating complicated malocclusions, by buccal expansion of approximately 2 to 4 mm achieved either to reduce crowding or to alter arch form.⁶ It is crucial that clinicians appreciate the effectiveness and consequences of Invisalign aligner-based arch expansion therapy on skeletal and dental components. Interdental width has previously been solely assessed for tooth crowns using 3D digital model measurements; however, the buccal movement of tooth roots and skeletal effects have not been assessed. The five studies included in the present review fulfilled the research criteria and evaluated the effectiveness and efficiency of maxillary arch expansion by clear aligners in adult patients, (mean difference between pre-treatment arch width and arch width after arch expansion) and the predictability of the planned arch expansion (mean difference between predicted and actual achieved arch expansion). In each of the five reports, pre-treatment and post-treatment digital models (.stl files) generated from an iTero scan were obtained. The models were used to compare the final generated virtual model in relation to the movements seen in the post-treatment model, by using the ClinCheck software.

In addition to the treatment efficiency and predictability of the planned arch expansion, molar inclination was evaluated by Lione et al.⁸ and Morales-Burruezo et al.⁹ Interdental gingival measurements were also taken into account by Houle et al.⁶ and Galluccio et al.,¹⁰ and molar rotation was additionally evaluated by Morales-Burruezo et al.⁹ The results of Zhou and Guo⁵ demonstrated that Invisalign aligners can achieve arch expansion, with efficiencies of $79.75 \pm 15.23\%$ at the canine cusp tip, $76.1 \pm 18.32\%$ at the first premolar cusp tip, $73.27 \pm 19.91\%$ at the second premolar cusp tip, and $68.31 \pm 24.41\%$ at the first molar cusp tip. The expansion efficiencies were marginally less than those reported by Houle et al.⁶ who indicated that the canine, first premolar crown, second premolar, and the first molar had expansion

efficiencies of 88.7%, 84.7%, 81%, and 76.6%, respectively. The accuracy of tooth movement for labial expansion of the anterior teeth was reported to be 40.5% by Kravitz et al.¹¹

The level of anticipated expansion determined the disparity in predictability between the groups. According to a Spearman correlation ($P = 0.05$), Zhou and Guo⁵ reported that the present expansion quantity and physiological expansion efficiency had a negative link. Houle et al. found that the overall accuracy of transverse changes in the upper arch was 72.8%, with 82.9% accuracy at the cusp tips and 62.7% accuracy at the gingival margins. With an accuracy of 88.7%, the canine cusp tip was the most accurate forecast which means that 0.22 mm of the 1.92 mm desired expansion was not attained. The accuracy was 52.9% at the gingival margin of the first molar.

Gingival margin measurements revealed that the lower canines had the most prediction error (62% accuracy), followed by the molars (85.5%), the first premolar (88.4%), and the molars at 70.7% overall. Since the amount of change required in the lower arch is typically less than in the upper arch, this could account for the higher outcome.⁶ The predictability data from Morales-Burruezo et al.⁹ suggested that the behaviour of aligners is comparable to that of conventional orthodontic arch wires, when considering deflection and inter-tooth distance. However, the system predictability results were not comparable.

Even though the identified studies were closely matched for sample size, there was no consideration of aligners made from the SmartTrack material. Furthermore, all of the patients received additional aligners (ranging from one to five phases of refinement treatment), and the system predictability results were not comparable.¹² Despite this, the study examined 64 patients (20 of whom had at least one tooth in crossbite) during the initial phase of therapy without the need for additional aligners, even though these were made of EX30 material.¹³

In summary, a steady decrease in the accuracy of the rate of expansion from the anterior to the posterior segment was observed in the five studies. This may be attributed to differences in root anatomy and cortical bone thickness, a higher occlusal load, greater soft tissue resistance in the posterior region, and a decline in mechanical efficiency from the anterior

to the posterior segments. The efficacy of expansive movement was substantially inversely related to the preset expansion quantity and the initial torque of the maxillary first molar.

In addition, the change in inter-canine, inter-first premolar, inter-second premolar, and inter-molar width after the aligner treatment was greater than the inter-canine, inter-first premolar, inter-second premolar, and inter-molar width before orthodontic treatment. The change in inter-canine, inter-first premolar, inter-second premolar, and inter-molar width after orthodontic treatment was less than that predicted by the ClinCheck software. At the end of an aligner treatment sequence, appliance efficiency may be slightly higher due to hysteresis, which is the lag between the expected and obtained results (the difference between the expected and the actual obtained expansion) of the Invisalign appliances. This lag is mostly related to energy loss that occurs during treatment because of the material's viscoelastic properties.

The present systematic review revealed that clear aligner treatment has potential benefits for orthodontic patients requiring arch expansion. To enable better and more effective aligner therapy, further research is needed to address issues as the average age of patients receiving treatment is steadily rising.

Limitations

The effectiveness and predictability of maxillary arch expansion in adult patients receiving clear aligner therapy were examined in the present systematic review. Retrospective and prospective studies were considered but case reports were excluded, and non-English language material was eliminated using a language filter. Due to their recency, heterogeneity, and non-comparable diagnostic techniques, all studies carried a significant risk of bias. The review assessed the outcome efficacy in spite of these drawbacks.

Conclusions

An area of focus has been the effectiveness of maxillary arch expansion in adult patients receiving clear aligner therapy. The hysteresis (lag) of the Invisalign devices may cause appliance efficiency to be slightly higher at the completion of an aligner treatment sequence. Over the course of treatment, the

maxillary arch's expansion rate declined progressively in the canine, premolar, and posterior regions, with the first and second premolars exhibiting the largest net expansion. When planning aligner arch expansion, a thorough assessment and overcorrection are crucial because the arch expansion efficiency is adversely correlated with the starting torque and level of required expansion. This strategy can assist in reducing the frequency of mid-course adjustments and revisions during the course of care.

Conflict of interest

The authors declare that there is no conflict of interest.

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