Effect of clear aligner attachment design on extrusion of maxillary lateral incisors: A multicenter, single-blind randomized clinical trial

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Introduction: Extrusion of maxillary lateral incisors during aligner treatment is a difficult movement to achieve accurately. Despite recommendations regarding attachment design, few studies and no prospective trials compare predictability among attachments. This study aimed to compare the efficacy between optimized and horizontal attachment designs for achieving maxillary lateral incisor extrusion during clear aligner treatment. **Methods:** The study included maxillary lateral incisors in 3 orthodontic practices requiring at least 0.3 mm of extrusion during the first series of 20-25 aligners in patients aged ≥16 years who were scheduled to begin clear aligner treatment (Invisalign; Align Technology, San Jose, Calif). Teeth were randomly assigned to receive optimized (O), rectangular horizontal nonbeveled (H), rectangular horizontal incisally-beveled (HIB), or rectangular horizontal gingivally-beveled (HGB) attachments. After the first series, a blinded evaluator measured extrusion using superimpositions with initial and predicted models. Linear models determined the difference in the predicted extrusion percentage achieved on the basis of attachment design. Other covariates were patient age, sex, number of trays, and self-reported compliance. **Results:** Forty patients (74 teeth) were enrolled, and 38 patients (71 teeth) completed the study. Intraexaminer and interexaminer reliability for extrusion measurements was high (intraclass correlation coefficient, 0.985 and 0.991, respectively). The achieved extrusion was significantly less than predicted (mean, 73%; $P < 0.0001$). The average achieved extrusion was 62%, 79%, 78%, and 78% for O, H, HIB, and HGB attachments, respectively, with H significantly more effective than O ($P = 0.0403$). Horizontal attachments (H, HIB, and HGB combined) were significantly more effective than O attachments ($P = 0.0060$), with an average difference in achieved extrusion of 14% of the predicted amount (95% confidence interval, 4-23; estimated 76% vs 62%). Horizontal attachments were an estimated 22% more effective than O attachments for extruding maxillary lateral incisors. **Conclusions:** Horizontal attachments are more effective than O attachments for predicted maxillary lateral incisor extrusion between 0.3 and 2.5 mm. The 3 horizontal attachment designs evaluated performed similarly for achieving predicted extrusion. **Trial Registration:** This randomized clinical trial was registered and reported at clinicaltrials.gov (NCT04968353). **Protocol:** The protocol was not published before trial commencement. **Funding:** This study was funded in part by the Alexander Fellowship of the Virginia Commonwealth University School of Dentistry, the Southern Association of Orthodontists, and the Virginia Orthodontic Education and Research Foundation. No funding source influenced the study design, the collection, analysis or interpretation of data, writing of the report, or the decision to submit the article for publication. (Am J Orthod Dentofacial Orthop 2023;■:■-■)

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Many adults are pursuing orthodontic treatment and seeking a more esthetic and comfortable option than conventional fixed appliances.[1] Advancements in intraoral scanning, digital treatment planning, and 3-dimensional (3D) technology, in general, have contributed to the increased popularity of clear aligner therapy.[2] Invisalign, the first digitally-based clear aligner system, was released >20 years ago as an esthetic, no wire, no bracket, alternative to traditional fixed appliances. Software is used to formulate a treatment plan, and computer-aided design and manufacturing stereolithographic technology to manufacture a series of clear aligners from a single digital impression.[3] The clear aligners are designed to be changed every 7 days, and Align Technology (San Jose, Calif) software programs each successive aligner to move and rotate teeth up to 0.25 mm or 2°, respectively.[4]

Since their introduction, ongoing improvements have increased the complexity of conditions that can be treated with clear aligners. Attachments were designed to improve the predictability of the tooth movements prescribed.[4,5] Studies reported that the overall predictability of specific tooth movements was 41% in 2009 and improved to 50% in 2020.[6,7] Similarly, single activations of conventional fixed orthodontic appliances rarely, if ever, result in perfect alignment. However, although orthodontists can adjust conventional fixed appliances to fine-tune treatment outcomes on a visit-to-visit basis, it is not possible to make similar adjustments during aligner treatment. Aligners are preprogrammed and often require rescanning of the dentition to manufacture another series of aligners to finish patients properly. Studies have reported that a majority of, or even all, aligner patients required at least 1 series of refinement trays to achieve desired results.[8-11]

Maxillary anterior teeth require the finest tooth positioning precision because those are the most easily visible to patients and practitioners.[12] To improve the predictability of various tooth movements with aligners, practitioners prescribe attachments to be bonded to those teeth requiring more control during treatment.[13] The first attachments introduced were ellipsoid in configuration, and they were largely replaced by more sharply defined and bulkier conventional attachments: horizontal, vertical, and beveled attachments, to improve control. Align Technology introduced optimized (O) attachments as a SmartForce feature to facilitate larger movements such as rotation >5° or extrusion >0.5 mm on certain teeth.[4] O attachments are typically smaller than horizontal attachments but are specifically designed to include a gap in the aligner to allow movement of teeth in the direction required and, thus, eliminate interferences to movement. However, a recent retrospective study found no significant differences in performance between conventional and O attachments for achieving desired rotational or extrusive movements.[14]

Because patients pursue aligner treatment instead of conventional fixed appliances because of perceived improvement in esthetics and comfort,[1] many practitioners may try to avoid placing large attachments on maxillary anterior teeth. Visible attachments were shown to detract from the esthetic acceptability of clear aligners.[15,16] Kravitz et al[6] observed that maxillary lateral incisors were the most common teeth requiring extrusion, and various experts recommend different, specific attachment designs and protocols for achieving difficult movements, including maxillary lateral incisor extrusion, more accurately during treatment.[17-20] A recent study found that O attachments for extruding maxillary lateral incisors were the type most highly preferred by general dentists, whereas orthodontists preferred gingivally-beveled horizontal (HGB) attachments.[21] No previous prospective studies have evaluated differences in the effectiveness between O and horizontal attachments for extrusion during orthodontic aligner treatment.

Specific objectives and hypotheses

This randomized clinical trial aimed to determine whether there were differences in the efficacy of extrusion of maxillary lateral incisors between O attachments and 3 horizontal attachment designs: horizontal nonbeveled (H), horizontal incisally-beveled (HIB), and HGB attachments. The null hypothesis was that there would be no significant differences in extrusion achieved among the attachment designs. Secondarily, the effects of patient age, sex, number of trays, and self-reported compliance on extrusion accuracy were analyzed.

MATERIAL AND METHODS

Trial design and any changes after trial commencement

The study design was a multicenter randomized clinical trial with 4 parallel arms. The Institutional Review Board at Virginia Commonwealth University (VCU) granted permission to conduct this study (VCU Institutional Review Board HM20021396). This randomized clinical trial was registered and reported at clinicaltrials.gov (NCT04968353). There were no

changes to the protocol after the trial commenced, but some modifications to the statistical analysis were made to combine study groups for reporting after preliminary analysis. Results were reported both before and after groups were combined.

Participants, eligibility criteria, and settings

Patients were recruited from the Department of Orthodontics at VCU and 2 private practice offices (Richmond [W.G.G.] and South Riding [N.D.K.]) in Virginia. Both private practice orthodontists were Invisalign VIP Diamond Plus Providers. Two orthodontists and VCU orthodontic residents treated all patients in the study. Patients were recruited at the time of their consultation if they met the study criteria: patients aged ≥16 years to be treated with either Comprehensive Invisalign or Invisalign Teen, at least 1 maxillary lateral incisor requiring ≥0.3 mm extrusion, maxillary arch with ≤6 mm of crowding or spacing, and all teeth present and fully erupted (excluding third molars). Exclusion criteria were: treatment plan requiring surgery or extraction of any maxillary teeth, maxillary lateral incisors with pathology or large restorations (crowns, veneers, etc), severely rotated maxillary anterior teeth (≥15°), and presence of anterior crossbite. Patients with poor tracking requiring midcourse intervention or failure to complete the aligners as prescribed were noted for reporting purposes but not included in the final analysis. Recruitment began in August 2021, and the final data collection was completed in June 2022.

Interventions

All patients received the same treatment they would have received were they not in the study, except that the designs of those attachments prescribed for maxillary lateral incisor extrusion during the first 20-25 aligners were assigned randomly. Each lateral incisor requiring extrusion of ≥ 0.3 mm was assigned to 1 of 4 different attachment groups: O, H, HIB, or HGB. Those 4 attachment designs were chosen on the basis of a previous study which identified those attachments as the ones preferred most often by practitioners (including orthodontic specialists and general dentists) to extrude maxillary lateral incisors during treatment with clear aligners.[21] All participants signed informed consent to participate in the study and were offered a $50 gift card at completion to compensate them for their involvement.

Invisalign's ClinCheck (Align Technology) software was used to design each patient's treatment sequence. Invisalign technicians were instructed to place O attachments. The orthodontist prescribed the horizontal (nonbeveled and beveled attachments) and removed O attachments if an O attachment was originally designated on a tooth randomly assigned for any other horizontal attachments. The movement limit was set to 0.25 mm maximum per aligner. Clinicians were permitted to change interproximal reduction prescriptions, tooth angulation, and attachments on teeth not included in this study and incorporate overcorrections, as preferred.

Patients were instructed to wear each aligner for a minimum of 22 h/d, 7 d/wk each, before moving to the next aligner, the standard aligner protocol used by the participating providers. Proper demonstration of aligner insertion as instructed was observed. Participants verbally confirmed compliance at each appointment, and compliance was self-recorded by participants in hours per day.

Conventional horizontal attachments (H, HIB, HGB) were designed to be 4 mm wide mesiodistally; the incisogingival dimension and the angulation were unaltered. Each attachment was placed in the incisal third and centered mesiodistally and incisogingivally. O attachments were used as received from Align. The protocol for attachment bonding was standardized using the commonly accepted bonding procedures.

Outcomes and any changes after trial commencement

Midcourse interventions to improve tracking, such as rescanning or introducing auxiliary appliances, were recorded and reported, but the teeth involved were not analyzed as part of the corresponding group. Maxillary lateral incisors not tracking, noted by a minimum of 1 mm of aligner material incisally when the aligner was fully seated, were recorded and reported but not analyzed within the group assigned.

Patients were evaluated only after the first series of aligners (20-25 aligners). After that, treatment proceeded as necessary, determined by patients and individual practitioners, and was not recorded. Only maxillary arches were evaluated in this study. Pretreatment scans were taken with iTero scanners and sent to Align Technology to initiate the ClinCheck. The predicted posttreatment ClinCheck stereolithography file was downloaded from Align Technology. In addition, an actual posttreatment iTero scan was taken after the first series of aligners. Stereolithography files of the pretreatment, actual posttreatment, and predicted posttreatment were transferred to GeoMagic Control X by 3D Systems (Rock Hill, SC). All models were standardized to a global XYZ coordinate system, with the z-axis representing the vertical axis.

The pretreatment models were used as the reference data model. The actual posttreatment and predicted posttreatment were used as the measured data models. The reference data model was divided into regions: posterior teeth, lateral incisors, central incisors, and gingiva. The posterior teeth region was used for the superimpositions. According to the method described by Grünheid et al,[22] a best-fit algorithm was used to superimpose 2 models (pretreatment to predicted posttreatment and pretreatment to actual post-treatment) to compare individual tooth movements planned and achieved in 3-dimensions with 50 iteration counts. The initial alignment algorithm was used before the best-fit algorithm for superimposition. After superimposition, the 3D compare tool was used to measure the vertical distance of each maxillary lateral incisor between the pretreatment and predicted posttreatment models and the pretreatment and actual posttreatment models. Measurements were made at 3 distributed points in the middle third of the incisal edge of the lateral incisor and averaged for the predicted extrusion and actual extrusion measurements.

The primary outcome was achieved extrusion relative to the predicted extrusion (percent achieved) of the maxillary lateral incisors among the 4 attachment groups (O, H, HIB, HGB). Secondary objectives included the analysis of age, sex, number of trays, and reported compliance related to extrusion accuracy (percent achieved).

After initial analysis, it was noted that the 3 horizontal attachment designs (H, HIB, HGB) performed similarly to each other compared to the O attachments. Because of the comparable clinical outcomes observed and their visible design similarities, analysis was also performed with the 3 conventional attachment designs combined, compared with O attachments. There were no other changes to the initial trial protocol.

Sample size calculation

Power analysis determined that 20 teeth/attachment would have 80% power to detect clinically meaningful attachment differences. Based on data from prior publications, the common standard deviation for extrusion was assumed to be 1.25.[23,24] A sample size of 20 per group could detect an effect size of 0.146 and a variance of means of 0.114. These estimates reflect small effect sizes and, therefore, could detect clinically meaningful differences in the extrusion ability among the 4 attachments.[25] Sample size calculations were estimated with nQuery (version 8.5.2; Statistical Solutions, Boston, Mass).

Interim analysis and stopping guidelines

Participants were informed that they could discontinue participation at any time and that it would not affect their remaining treatment. Patients with poor tracking requiring midcourse intervention or failure to complete the aligners prescribed were noted for reporting purposes but not included in the final analysis.

Randomization

The statistician generated a stratified, block randomization list using the Excel random number generator with blocks of 4 and stratified for the 3 practices based on anticipated recruitment from each practice (40, 30, and 10 teeth). Randomization was at the tooth level rather than by the patient. Attachment types were assigned when recruited patients consented to participate in the study. The attachment type for each tooth was revealed when the ClinCheck was received back from Align so clinicians could ensure that the appropriate attachment was prescribed: O, H, HIB, or HGB.

Blinding

A single evaluator completed the measurements and was blinded to the attachment used for each tooth. Blinding of the treatment providers and patients was not possible. Digital pretreatment, prediction, and posttreatment models were deidentified for each tooth involved. Attachments were removed from the maxillary lateral incisors for the final scan to ensure blinding during the superimposition and measurement process.

Statistical analysis

Intraexaminer and interexaminer reliability were calculated using the intraclass correlation coefficient (ICC) and the repeated measurements for the predicted and actual extrusion. In addition, superimposition with and without palatal rugae was compared for actual extrusion measures using ICC. Bivariate analyses were conducted to determine if the 4 treatment groups were equally balanced regarding patient sex, predicted extrusion, patient age, and self-reported compliance. These analyses were conducted using the Fisher exact test and analysis of variance methods on the basis of the variable type. The difference between actual and predicted extrusion was compared using a paired *t* test. Linear models were used to determine the difference in the percent of the predicted extrusion achieved on the basis of the attachment after adjusting for covariates. Covariates of interest included were patient age, sex, number of trays, and self-reported

compliance (average hours of aligner wear per day). Clustering was used in the analysis to account for patients with 2 teeth involved in the study, usually randomly assigned to different attachment groups. All pairwise comparisons were adjusted using Tukey's adjustment to account for multiple comparisons. SAS Enterprise Guide was used for all analyses (version 8.2; SAS Institute, Cary, NC). The significance level was set at 0.05.

Error of the method

After 2 weeks, the measurements for 14 models (25 teeth) were repeated, and intraexaminer reliability was evaluated. This involved performing the pretreatment to prescribed posttreatment and pretreatment to posttreatment superimposition procedures again and remeasuring the outcomes. Interexaminer reliability was established by having a second blinded examiner superimpose and measure the 14 models (25 teeth).

A subsample of 10 teeth was measured for extrusion by superimposing with and without the palatal rugae as stable landmarks to quantify the potential measurement bias introduced by superimposing models on the posterior teeth. [26,27] This was done because the rugae were removed during ClinCheck processing and were absent in the predicted posttreatment models. The differences in the extrusion with and without the rugae were compared with 2 one-sided *t* test method. Equivalence bounds were preset at 0.1 mm and evaluated at the 0.05 level to generate 90% equivalence bounds.

RESULTS

Participant flow

Sixty-eight patients were assessed for eligibility for this study. Three patients declined to participate. Forty patients (74 maxillary lateral incisors) met the inclusion criteria and were enrolled in the clinical trial. A total of 71 maxillary lateral incisors from 38 patients were included in the final analysis. One patient (2 maxillary lateral incisors: H, HGB) was excluded because of poor tracking and inadequate compliance and switched to braces. One patient (1 maxillary lateral incisor: HGB) had poor compliance and tracking, requiring midcourse correction. The last data collection was in June 2022. The Consolidated Standards of Reporting Trials Guidelines flow diagram is presented in Figure 1.

Baseline data

Of the 71 maxillary incisors included in the study and analyzed, 23 (32%) were randomly assigned and treated using O attachments, 19 (27%) with H, 15 (21%) with HIB, and 14 (20%) with HGB. The predicted (prescribed) extrusion ranged from 0.31 mm to 2.46 mm, with an average of 0.84 mm, and did not differ significantly among the 4 groups ($P = 0.2550$). The distributions of patient sex, age, number of trays, and self-reported compliance did not differ significantly among the 4 attachment groups. The baseline characteristics of the 4 attachment groups are presented in Table I.

Primary and secondary outcome analyses

Intraexaminer and interexaminer reliability for extrusion measurements was calculated and found to be very high (ICC, 0.985 and 0.991, respectively). The average intraexaminer measurement difference between evaluations was −0.006 mm (95% confidence interval [CI], −0.017 to 0.004). The average interexaminer measurement difference between evaluations was 0.002 mm (95% CI, −0.014 to 0.019). Extrusion measurements were, on average, 0.03 ± 0.12 mm larger without the palatal rugae for reference. Results from the equivalence testing determined the 2 measures (superimposition on the best fit of posterior teeth and superimposition on palatal rugae) were equivalent within the preset bounds of 0.1 mm (90% equivalence bounds, −0.09 to 0.03).

The amount of actual extrusion achieved was significantly less than the predicted extrusion by an average of 0.21 mm (95% CI, 0.17-0.25; $P < 0.0001$). The average achieved extrusion was 73% of the predicted extrusion (95% CI, 68-78). A graphical depiction of the association between actual and predicted extrusion by attachment type is shown in Figure 2.

The amount of extrusion achieved compared with the predicted was significantly associated with the attachment type ($P = 0.0240$). Although the overall test was significant, the only pairwise comparison (adjusted for multiple comparisons) that yielded a statistically significant comparative difference was the H vs O attachment with an average difference of 17% of the predicted extrusion (95% CI, 1-33; $P = 0.0403$). Teeth with H attachments extruded an average of 79% ± 21% of the predicted amount, compared with O attachments at 62% ± 22%.

Because the 3 horizontal attachment designs were similar in shape and clinically demonstrated an estimated average extrusion of 79%, 78%, and 78% (for H, HIB, and HGB, respectively), compared with the O attachment at 62%, the 3 conventional attachments were combined into 1 group, and the model was refit. This full model used clustering to account for instances when 2 teeth from the same patient were involved in the

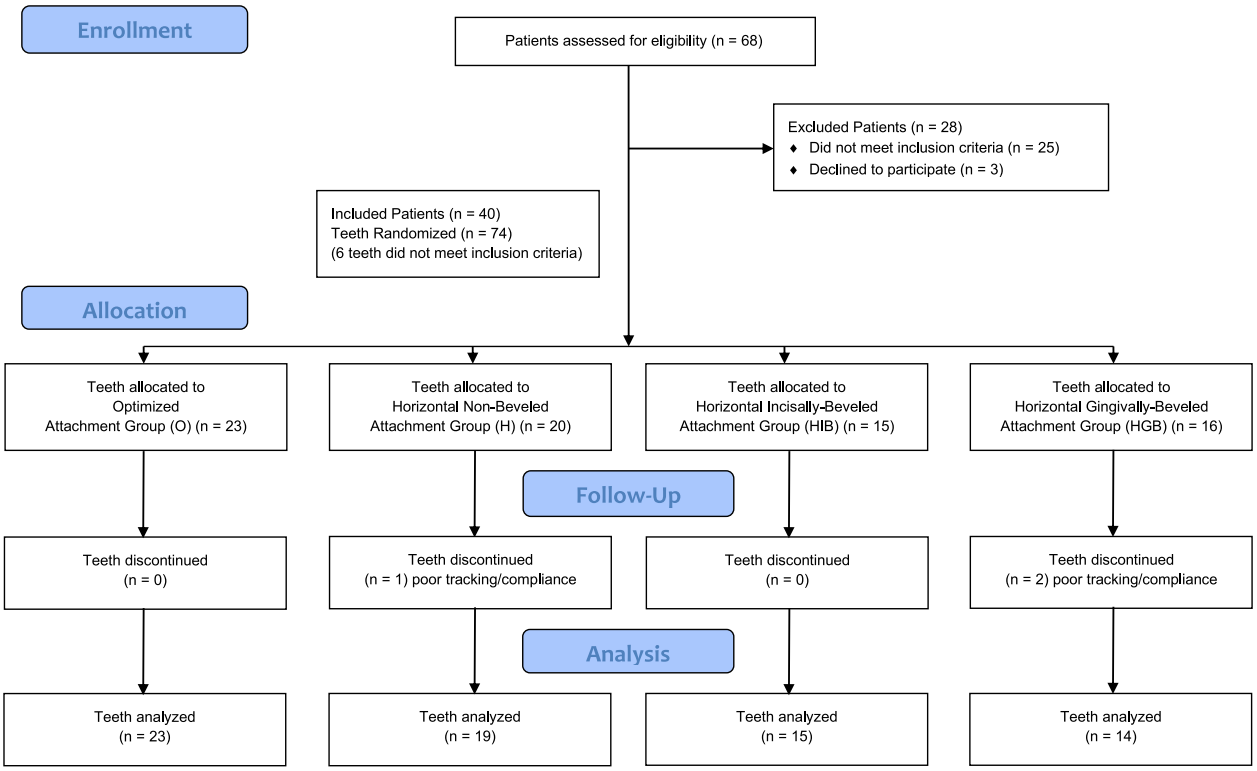

Fig 1. Consolidated Standards of Reporting Trials flow diagram.

Table I. Characteristics of attachment groups at baseline

Characteristic	*O (n = 23)*	*H (n = 19)*	*HIB (n = 15)*	*HGB (n = 14)*	P *value*
Predicted extrusion, mm	0.7 ± 0.3	0.9 ± 0.4	0.9 ± 0.5	0.9 ± 0.6	0.2550
Age, y	32.1 ± 14.3	30.4 ± 15.2	31.4 ± 15.0	31.2 ± 15.6	
No. of trays	21.7 ± 2.3	22.4 ± 3.8	23.7 ± 4.2	22.6 ± 3.9	
Compliance, h/d	17.9 ± 4.2	17.3 ± 3.9	18.1 ± 3.7	18.7 ± 1.8	
Sex (female, male)	14, 9	13, 6	13, 2	11, 3	

Note. Values are presented as mean ± standard deviation.

study and was adjusted for the number of trays, patient age, patient sex, self-reported compliance, and a variable to indicate horizontal vs optimized attachment. The attachment type (horizontal vs O) was significantly associated with achieved extrusion ($P = 0.0060$). On average, horizontal attachments achieved an estimated 76% of predicted extrusion, compared with optimized attachments, which achieved 62% of predicted extrusion. This 14% difference (95% CI, 4-23) equated to an estimated 22% improvement using a horizontal attachment design compared with an O attachment for maxillary lateral incisor extrusion. None of the other factors were significantly associated with achieved extrusion. Results of the full refit model are presented in Table II.

Harms

There were no adverse effects reported during the study period. Two patients did not complete the first series of trays as prescribed, and the 3 teeth enrolled in the study from these patients were not analyzed. However, those patients resumed comprehensive orthodontic treatment, one with conventional fixed appliances and the other with aligners.

DISCUSSION

Main findings in the context of the existing literature, interpretation

This was the first randomized clinical trial comparing the efficacy of various attachment designs on achieving

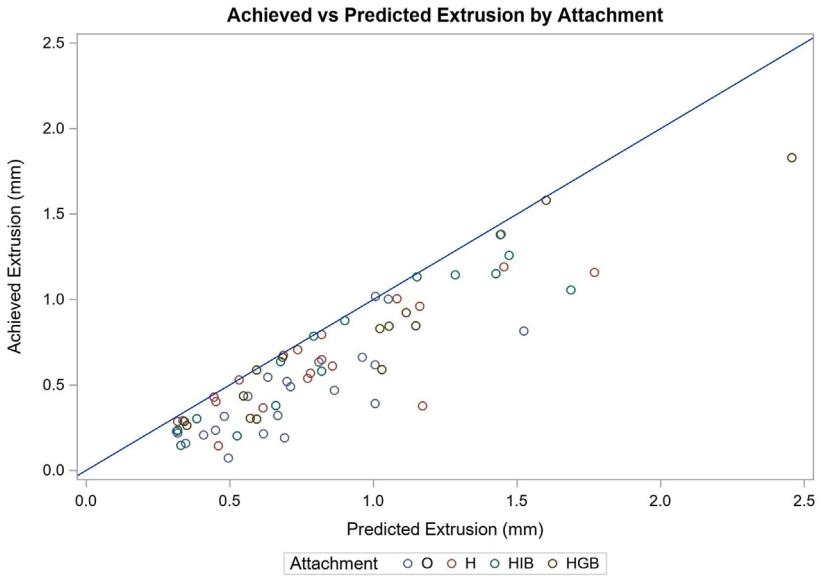

Fig 2. Achieved vs predicted extrusion for the 4 attachment designs. Note that points below the diagonal line indicate achieved extrusion less than prescribed.

Table II. Full repeated measures model predicting achieved extrusion, adjusting for attachment, patient age, sex, number of trays, and self-reported compliance

Variables	*Estimate*	*95% CI*	P *value*
Intercept	0.50	0.02-0.97	0.0410
Attachment			
Horizontal	0.14	0.04-0.23	0.0060
Optimized	Reference		
Sex			
Female	0.08	−0.04 to 0.21	0.1832
Male	Reference		
No. of trays	0.01	−0.01 to 0.02	0.4158
Age (10 y increase)	−0.04	−0.08 to 0.00	0.0538
Compliance	0.00	−0.01 to 0.02	0.6350

Note. H includes H, HIB, and HGB combined.

maxillary lateral incisor extrusion during aligner treatment. Attachments were introduced to increase aligner retention and improve control of various tooth movements.[1,4,5,28] A systematic review recommended that additional-novel attachments might improve the effectiveness of Invisalign for various movements, including maxillary incisor extrusion.[29] However, a more recent systematic review specifically examining the effects of attachments on clear aligner therapy concluded that there was a lack of evidence to support the role of attachments in improving control of extrusion or vertical movements in general, though they were deemed effective for achieving other movements; it was specifically noted that larger attachments with sharper edges seemed to be more effective for controlling tooth rotation.[30] In addition, an in vitro study found that rectangular beveled attachments significantly improved aligner retention compared with ellipsoid or no attachments.[31] This was consistent with the findings of this study, in which the larger, conventional rectangular attachments were significantly more effective in accomplishing maxillary lateral incisor extrusion as prescribed.

It was previously reported that extrusion was the most difficult type of tooth movement to control with aligners.[32] Kravitz et al[6] observed that incisor extrusion was the least accurate movement, with the maxillary lateral incisors extruding only 28.4% of the amount prescribed. A follow-up study 11 years later showed improvement to 53.7%.[7] In contrast, a retrospective study evaluating the accuracy of clear aligners reported that maxillary incisor intrusion was the least accurately predicted movement, whereas incisor extrusion did not differ significantly from what was intended.[33] Krieger et al[34] found that all changes in the anterior region after aligner wear were within acceptable bounds except for improvement of overbite. Al-Nadawi et al,[35] in a randomized clinical trial, found no differences in effectiveness for any incisor movements, including incisor extrusion, when comparing a 7-day to 14-day wear protocol for aligners. In this trial, we observed an estimated effectiveness of 76% with conventional rectangular horizontal attachments (beveled or not)

and 62% with O attachments for maxillary lateral incisor extrusion, using the commonly accepted, 7-day wear protocol, thus equating to a 22% improvement in effectiveness for rectangular compared with O attachments. The studies described demonstrated general improvement in outcomes over time as aligner treatment strategies and materials evolved. In addition to attachment design, differences in effectiveness among studies could also be affected by the amount of movement prescribed, length of treatment or number of trays evaluated, participant cooperation in wearing aligners, and other study design factors.

Adults seeking orthodontic treatment consider appliance esthetics, discomfort, and cost, among other factors, in selecting a treatment modality.[1] Lingual fixed appliances have the best esthetic appearance among orthodontic options, but aligners offer superior comfort and adaptability.[36] Interestingly, the number of teeth with lingual attachments was the most influential factor in patients reporting negative experiences during aligner treatment.[37] However, compared with traditional fixed buccal appliances, altered speech production persists longer for patients wearing aligners.[38] Although aligners have been shown to be more esthetically acceptable than conventional orthodontic appliances, the appearance of visible attachments attracted attention and reduced the esthetic acceptability of aligners.[15,16,37] Using larger, conventional rectangular attachments may improve the predictability of certain movements, such as the extrusion of incisors, but may also be more obvious to observers. One study found that evaluators preferred the appearance of ceramic brackets to aligners when accompanied by multiple attachments,[15] whereas most participants agreed they would accept reduced appliance esthetics if a better outcome could be achieved. Another study found no significant differences during treatment for quality of life reported in adolescents between fixed appliances and aligners, though females using Invisalign said they felt more attractive.[39]

This study evaluated lateral incisor extrusion by superimposing digital models (actual and predicted) using the posterior region as a stable reference, as done in a previous study.[22] It was anticipated that little or no posterior tooth movement would occur in the short timeframe analyzed (20-25 sets of aligners). Align Technology software (ClinCheck) removes the palatal tissue during processing, so the validity of this assumption was checked by using the rugae to superimpose the actual pretreatment and posttreatment models and compare the results with superimpositions done using the posterior region.[26,27,40] This would be analogous to superimposing the initial actual and starting ClinCheck models and digitally transferring the palatal tissue to serve as a reference. Results showed minimal differences averaging 0.03 mm between the 2 methods, within the preset equivalence bounds of 0.1 mm.

Limitations

This study was designed to evaluate the efficacy of small extrusive movements prescribed for maxillary lateral incisors during aligner treatment, thus limiting the direct application of the findings to patients requiring similar magnitudes of extrusion. Predicted extrusion averaged 0.84 mm (range, 0.31 to 2.46 mm), with the extrusion achieved being 73% of what was predicted. Importantly, the study did not evaluate the ability of aligner treatment to achieve actual treatment goals for individual patients. Practitioners may have intentionally prescribed overcorrections for extrusion, anticipating that the appliance would not deliver 100% of the amount predicted.

Only vertical movements of the maxillary lateral incisor incisal edge were evaluated in this study. Buccal or palatal displacements or inclination changes may have been prescribed intentionally or occurred inadvertently, but they were not assessed because the objective was to evaluate maxillary lateral incisor extrusion. Participating clinicians were not instructed to restrict other types of movement that they judged to be needed for individual patients. In addition, it is possible that other factors, such as initial spacing or crowding in the arch, could have affected extrusive movements during alignment, but these occlusal characteristics appeared to be evenly distributed among the attachment groups studied.

Another possible limitation of this study was the reliance on participating patients to wear their aligners as prescribed. Though compliance was checked at each visit and reported verbally by patients, there was no objective measurement of compliance other than the failure of the aligners to track properly, as noted at follow-up visits. Reported compliance averaged 17-19 h/d, despite requesting 22 h/d of wear. In addition, it is known that actual compliance is generally lower than reported compliance, but self-reporting is still generally considered a useful assessment.[41,42] Two patients (3 teeth) were excluded because of inadequate compliance and poor tracking.

Generalizability

The results of this study can be applied to compliant orthodontic patients undergoing Invisalign treatment for mild malocclusions with a prescription for maxillary lateral incisor extrusion of between 0.3 and 2.5 mm.

CONCLUSIONS

1. Horizontal attachments (H, HIB, or HGB) were significantly more effective at achieving prescribed maxillary incisor extrusion (76% of the predicted amount) compared with O attachments (62% of the predicted amount) in patients with mild malocclusion undergoing Invisalign treatment.
2. The 3 horizontal attachment types performed similarly to achieve prescribed extrusion.

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