Predictability of incisal labiolingual inclination, overjet, and overbite changes, and the prevalence of open gingival embrasures in patients with mandibular incisor extraction treated with Invisalign: A retrospective cohort study

Keith Chan,[a] Tony Weir,[a] Elissa Freer,[a] Desmond Ong,[a] and Hien Nguyen[b]
Brisbane, Queensland, Australia

Introduction: This retrospective study aimed to assess differences between the planned Invisalign (Align Technology, San Jose, Calif) ClinCheck tooth movements and the achieved outcomes for patients with single mandibular incisor extraction with respect to overjet, overbite, and labiolingual inclination for the initial series of aligners and to assess the prevalence of open gingival embrasures (OGEs) in the former extraction sites. **Methods:** The records of 83 patients who received Invisalign treatment with extraction of a single mandibular incisor were evaluated. The predicted and achieved overjet and overbite measurements were compared using the Invisalign ClinCheck software. The prevalence of an OGE was assessed visually using posttreatment digital models. The labiolingual inclination of the mandibular incisors was measured through superimposition of the pretreatment, predicted posttreatment, and achieved posttreatment digital models using Geomagic Control X (version 2018 1.0; 3D Systems, Rock Hill, SC) metrology software. **Results:** Differences between predicted and achieved labiolingual inclination changes of the mandibular incisors were minor in the lingual direction (90.4%); however, planned labial movements were significantly underexpressed (59.0%). A comparison of the predicted and achieved overjet values revealed a clinical expression of 49.6% and 76.0% when the overjet was planned to decrease and increase, respectively. With respect to the predicted and achieved overbite changes, no significant difference was found when the overbite was predicted to increase. In contrast, when the overbite was predicted to decrease, only 50.5% of this planned overbite reduction was clinically achieved. Most patients (95.2%) displayed an OGE in the former extraction space. **Conclusions:** Extraction of a single mandibular incisor in conjunction with Invisalign treatment resulted in an underexpression of the predicted proclination of the mandibular incisors, overjet changes, and overbite reduction. The development of an OGE was highly probable after the initial CAT aligner series. (Am J Orthod Dentofacial Orthop 2025;168:199-209)

Fundamental components of orthodontic treatment include correcting the labiolingual inclination of the teeth,[1] in addition to achieving an ideal overbite and overjet.[2,3] Correct labiolingual inclination of the incisors is required to prevent the overeruption of teeth and to provide appropriate positioning of contact points.[1] Alteration in the labiolingual inclination of teeth also contributes to changes in the dimensions of the anterior overbite and overjet. Retroclination of the incisors tends to deepen the bite,[4,5] whereas proclination of the incisors tends to

[a]Discipline of Orthodontics, School of Dentistry, The University of Queensland, Brisbane, Queensland, Australia.
[b]School of Mathematics and Physics, The University of Queensland, Brisbane, Queensland, Australia

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Address correspondence to: Tony Weir, Discipline of Orthodontics, School of Dentistry, The University of Queensland, 288 Herston Rd, Herston, Queensland 4006, Australia; e-mail, tony@tonyweir.com.au.

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reduce the overbite.[6] Similarly, changes in the inclination of the maxillary and mandibular incisors will influence the overjet.[7]

Although the demand for clear aligner therapy (CAT) has increased significantly over recent years,[8,9] concerns have arisen regarding the efficacy of CAT. When compared with fixed appliances, outcomes from comparison studies have shown mixed results. Poorer outcomes have been reported for CAT[10,11] by some researchers, along with significant differences between the predicted and the achieved outcomes.[12-14] A 2022 meta-analysis by Yassir et al[15] comparing CAT with fixed appliance treatment reported that CAT was effective for mild to moderate malocclusions, although it was associated with inferior outcomes when treating severe malocclusion or with achieving specific tooth movements.

CAT was initially developed to address relatively simple treatment objectives, such as closing minor spaces and resolution of mild to moderate crowding. In contemporary practice, clinicians attempt to manage patients with more complex requirements using CAT.[8,9] Several case reports have demonstrated the ability of Invisalign to treat patients with mandibular incisor extraction.[16-18] A recent metrology study by Truong et al,[19] employing the same sample as this study, investigated the mesiodistal tip of mandibular anterior teeth after CAT for mandibular incisor extraction patients. They found an average efficacy of 78.9% in achieving the planned mesiodistal tip of mandibular incisors.

Specific indications for a mandibular incisor extraction may include the following: patients with a Class I or Class III molar relationship in which nonsurgical treatment of Class III malocclusion is deemed to be appropriate, a significant Bolton mandibular tooth size excess, moderate to severe crowding in the mandibular anterior region, reduced or normal overbite and overjet, acceptable soft tissue profile esthetics and poor prognosis of a mandibular incisor.[16,20]

Extraction of a single mandibular incisor in conjunction with orthodontic treatment may result in an open gingival embrasure (OGE) in the extraction site, which may be considered unesthetic. It has been reported that 68% of patients with mandibular incisor extraction develop an OGE, which is significantly higher than the reported 22%-38% incidence of OGEs with other adult orthodontic treatment options.[21,22] When comparing CAT with fixed appliance treatment, Yang et al[23] found that patients treated nonextraction with CAT had a 1.5-2.0-fold greater likelihood of developing an OGE. The potential risk factors for developing an OGE with fixed appliance treatment of patients with mandibular incisor extraction have been identified as including lingual movement of the incisors, pretreatment overlap of the incisors, a large distance (>5 mm) between the contact point of the teeth to the alveolar crest after treatment, a large amount of intrusion of the mandibular incisors, divergent root angulation, embrasure areas >5.09 mm^2, having triangular crown morphology, and being an adult patient.[21,22,24] These factors are also likely to apply to CAT.

Despite the increasing number of CAT studies in the literature, most of these studies involve nonextraction CAT, which seems to indicate the treatment of milder malocclusions.[25] This study analyzed the outcomes of mandibular incisor extraction orthodontic treatment with Invisalign (Align Technology, San Jose, Calif). This study aimed to determine the predictive accuracy of Align Technology's ClinCheck treatment planning software for overbite, overjet, and labiolingual inclination changes for the initial treatment series of aligners and to record the prevalence of OGE in the former extraction site after Invisalign treatment involving extraction of a single mandibular incisor.

MATERIAL AND METHODS

The sample was retrospectively extracted from the Australasian Aligner Research Database, which comprises approximately 17,000 CAT patients submitted by 17 orthodontists with experience in CAT. To reduce the risk of selection bias, clinicians contributing to this database must submit every treated case irrespective of the quality of the outcome achieved. All eligible patients in the database were included for analysis to minimize selection bias. The inclusion criteria were (1) patients with extraction of a single mandibular incisor and no other therapeutic mandibular arch extractions, (2) treatment with Invisalign SmartTrack aligners only, (3) patients aged >18 years at the commencement of treatment to reduce the effect of growth over the orthodontic treatment outcome, and (4) complete stereolithography (STL) files of the pretreatment, predicted digital outcome from Align Technology's proprietary ClinCheck software and final digital models after the initial series of aligners.

Eligible patients from the database (ie, who satisfied the above inclusion criteria) were excluded from this study if any of the following issues were detected: (1) restorative procedures were provided during treatment, (2) orthognathic surgery was performed, and (3) consumption of medication that may affect bone metabolism

The pretreatment (T0) predicted posttreatment (T1) and achieved posttreatment (T2) overjet and overbite information, along with the types of attachments used, were obtained from the patient's ClinCheck files. The

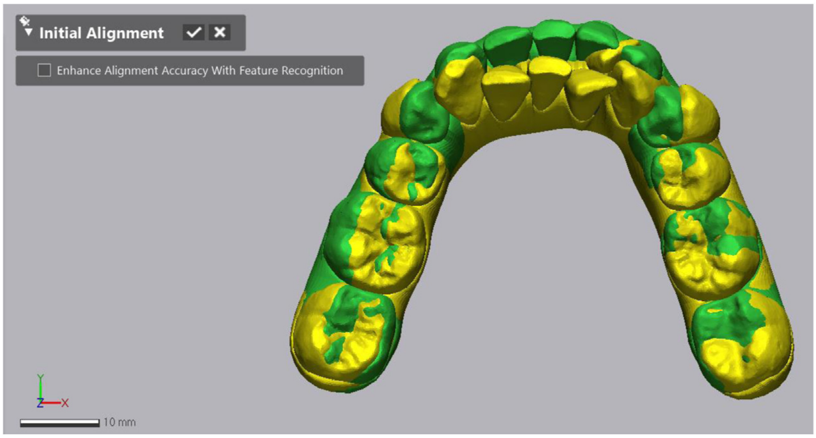

Fig 1. Initial alignment of models using Geomagic Control X software. *Yellow*, reference model (T0); *green*, measured model (T1).

accuracy of these specific measurements has been previously validated.[26] Similarly, the anterior and overall Bolton ratio values were acquired from the ClinCheckfiles, with the accuracy of these features also previously validated.[27] Assessment of the labiolingual inclination of the incisors was adapted from the methodology used by Gaddam et al[28] and Bowman et al.[29] T0, T1, and T2 digital models were sourced for each patient and exported as STL files through ClinCheck. The T0, T1, and T2 STL files were subsequently imported into Geomagic Control X (3D Systems, Rock Hill, SC) and were superimposed on the T1 models. Superimposition was performed using the initial alignment function (Fig 1), and the registration was refined with the best-fit alignment with a 50-iteration count and an 80% sampling ratio (Fig 2). A reference plane was constructed by establishing a plane via the Geomagic Control X algorithm for the Y-axis of the Cartesian system of the reference model through the mandibular incisors (Fig 3). The long axis of each mandibular incisor was autogenerated using the flood-selection tool (Fig 4). This tool identifies the specific object—in this instance, a mandibular incisor and takes all the scanned points on the crown surface (up to 1500 per tooth) to construct, via an algorithm, a long axis for the selected shape unique to that shape. The digital models were hidden to facilitate viewing of the vector and plane. The presence of an OGE was assessed visually on T2 digital models by the first researcher (K.C.). Any visible space in the gingival embrasure on the digital model, when viewed from the labial, was recorded as an OGE being present.

Subsequently, the angle between each vector and the reference plane was measured (Fig 5) to determine the inclination of each incisor relative to the reference plane.

Changes that led to an increase in the parameters of overjet, overbite, or labiolingual inclination were assigned a positive value, whereas a decrease in these parameters was assigned a negative value. If the predicted change was equal to 0, it was included in both the positive and negative subgroups.

Statistical analysis

Sample size estimation was calculated using G* Power (version 3.1.9.7; University of Düsseldorf, Düsseldorf, Germany) and based on previously published literature,[28] which found a mean difference of 2.75° (standard deviation = 5.7°) between the predicted and achieved labiolingual inclination of mandibular incisors. The calculation indicated that for a study with a power of 90% and an α error of 0.05, a minimum sample of 39 subjects would be needed. Statistical analysis was performed using R programming language (version 4.3.3; R Core Team, Vienna, Austria). Paired t tests were used to assess equivalence in the predicted overbite, overjet, and labiolingual inclination changes and the achieved overbite, overjet, and labiolingual inclination changes, respectively. Linear regression tests were used to examine the potential influence of treatment duration, age and gender, with respect to the difference between predicted and achieved movements. A chi-square test was used to investigate whether the presence of various aligner attachments affected the development of an OGE in the former extraction site.

RESULTS

Table 1 shows the characteristics of the sample.

Twelve patients were excluded because of missing information. This resulted in a final sample consisting of 83

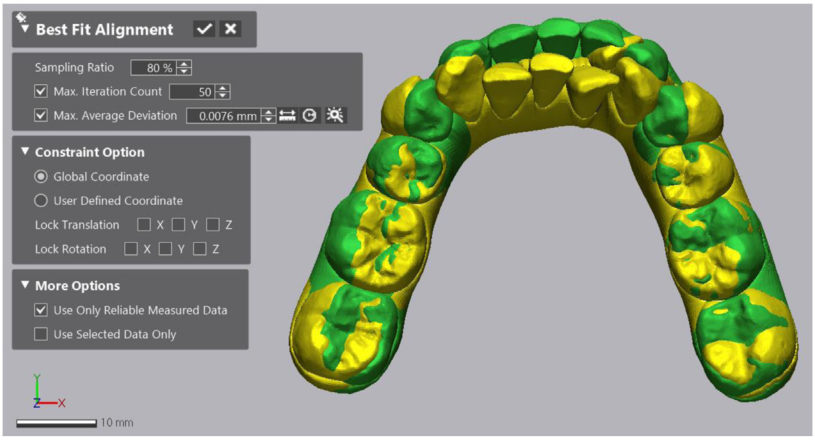

Fig 2. Best-fit superimposition of models using Geomagic Control X software. *Yellow*, reference model (T0); *green*, measured model (T1).

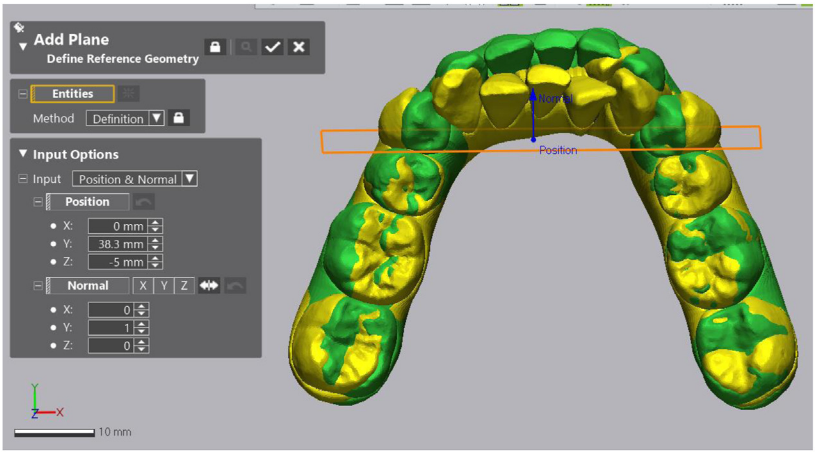

Fig 3. Construction of reference plane using Geomagic Control X software. *Orange*, reference plane in the y-axis.

patients with 27 male subjects and 56 female subjects (Table I). The mean age of the sample was 37.1 years. The mean treatment duration was 52.8 weeks, and the mean number of aligners prescribed for treatment was 34.2%. A significant anterior tooth size discrepancy >2 mm was detected in 18.1% of patients, and 27.7% of patients had a significant overall tooth size discrepancy >2 mm. The types of attachments and power ridges used were quantified, with the vertical rectangular types the most commonly employed, being prescribed on 147 teeth (59%). Power ridges were prescribed for only 2 teeth (0.8% of the total sample).

Assessment of the differences in predicted and achieved overjet, overbite, and labiolingual inclination were divided into positive predicted changes and negative predicted changes as described in the Material and Methods (Table II).

In the positive subgroup of labiolingual inclination changes, the predicted labiolingual movement was significantly higher than the achieved labiolingual movement. On average, the magnitude of the achieved inclination changes was 3.2° (95% confidence interval, 2.2°-4.3°) less than the predicted inclination changes (Table II) with a mean accuracy of 59.0%. In the negative subgroup for labiolingual inclination changes, the mean difference between the predicted and achieved movement was only 0.5° (95% confidence interval, −0.9°-1.8°) and was found to be statistically insignificant ($P > 0.5$). When an increase in overjet was planned, there was a tendency for the predicted overjet increase to be greater than the achieved overjet increase, with the prediction having a mean accuracy of 76.0%. When a decrease in overjet was planned, the magnitude of the predicted overjet decrease was significantly greater

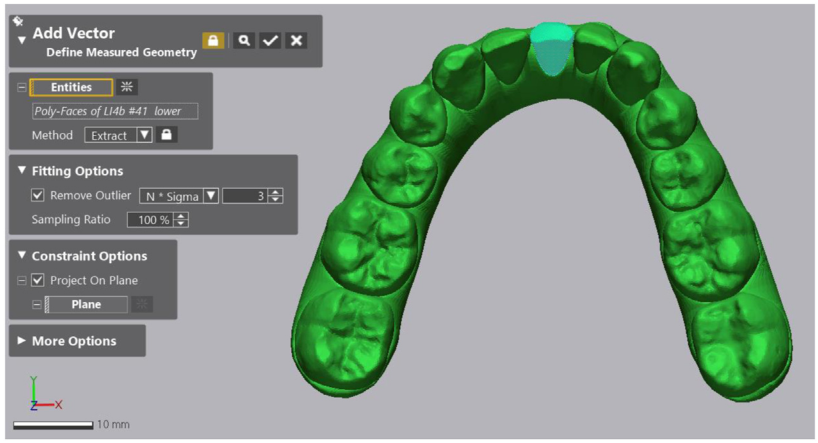

Fig 4. Flood selection of the mandibular incisor (*pale green*) before derivation of a long-axis analog vector.

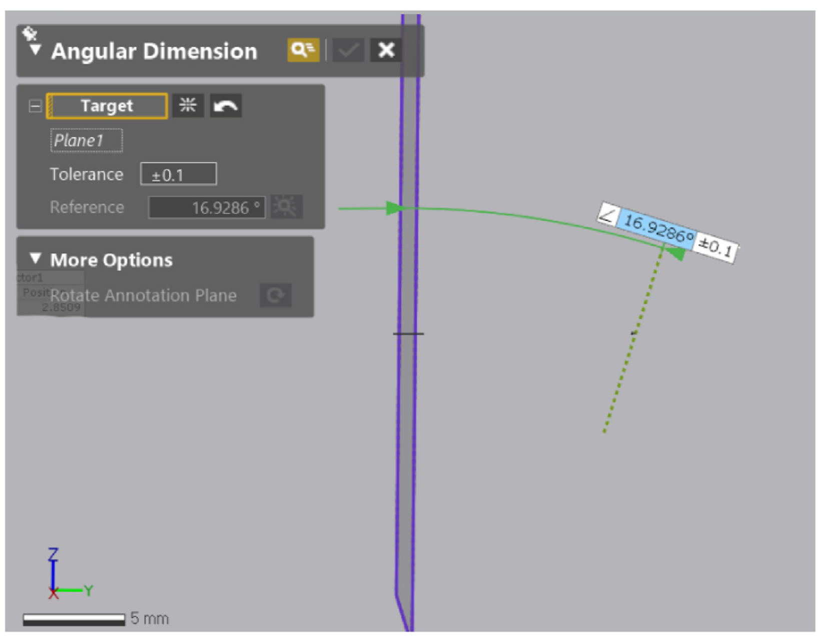

Fig 5. Angular measurement between the reference plane (*purple*) and the long-axis vector of the flood-selected mandibular incisor (dotted *green* line).

than the magnitude of the achieved overjet decrease ($P < 0.001$), with the prediction of overjet decrease having a mean accuracy of 49.7%. When an increase in overbite was planned, there was no significant difference between the predicted and achieved overbite changes. However, when a decrease in overbite was planned, the achieved overbite change was significantly less than the planned overbite change ($P < 0.001$), with only 50.5% of the intended overbite reduction being clinically expressed. It was noted that 95.2% of patients had an OGE in the position of the formerly extracted mandibular incisor. There was no association between the attachment type used and the presence of an OGE.

Linear regression analysis revealed no significant association between gender, age, the number of aligners, treatment duration, or aligner wear schedule (ie, 1 weekly or 2 weekly changes), and the predictability of overjet changes when an increase in overjet was planned (Table III). In contrast, when a decrease in overjet was planned, age did demonstrate a significant association with respect to the difference between the predicted and achieved overjet change. On average, for every additional year of age, the

Table I. Descriptive statistics

Variable	*Patients (n = 83)*
Age (y)	37.07 ± 13.63
Gender	
Female	56 (67.47)
Male	27 (32.53)
Time of wear	
1-weekly	23 (27.71)
2-weekly	50 (60.24)
Overall treatment length (wk)	52.78 ± 15.99
Initial aligners	34.17 ± 10.49
Tooth extracted	
42	11 (13.25)
41	30 (36.14)
31	37 (44.58)
32	5 (6.02)
Attachment type	
Nil	82 (32.93)
Rectangular	
3 mm	63 (25.30)
4 mm	61 (24.50)
5 mm	23 (9.24)
Optimized extrusion	3 (1.20)
Sash	15 (6.02)
Other	
Power ridge	2 (0.80)
Anterior tooth size discrepancy >2 mm	
Yes	15 (18.07)
No	68 (81.93)
Overall tooth size discrepancy >2 mm	
Yes	23 (27.71)
No	60 (72.29)

Note. Continuous variables are presented as mean ± standard deviation, whereas categorical data are shown as frequency (percentage).

achieved overjet would be 0.031 mm lower relative to the predicted overjet (Table III).

Linear regression analysis showed that the factors assessed did not significantly influence the difference between predicted and achieved overbite changes, irrespective of whether a positive or negative overbite change was planned (Table III).

Similarly, no factors were shown to significantly influence the difference between predicted and achieved labiolingual movements when either a positive or negative change was planned (Table IV).

Figure 6 presents a drop plot of the predicted vs achieved labiolingual inclination for all patients. It illustrates a trend for the higher predicted labiolingual inclination changes, the lower the achieved inclination. Lower predicted inclinations tend to result in more overexpression of labial movement.

DISCUSSION

This study analyzed the predicted and achieved outcomes for 83 adults who underwent Invisalign CAT in conjunction with the extraction of a single mandibular incisor. Most patients (64.47%) were females, and the mean age of the sample was 37.1 ± 13.6 years. These characteristics are considered to be representative of samples commonly treated with CAT.[29] This sample was identical to that used in the study by Truong et al[19]

The findings indicated that differences between the predicted and achieved labiolingual inclination changes depended on whether the planned change occurred in the labial or lingual direction (Fig 6). When a labial movement was planned, there was a significant shortfall in the clinical expression of the achieved movement. The mean positive predicted labiolingual inclination change was 7.9°; however, the achieved labiolingual inclination change was only 4.7°. This 3.2° shortfall represents a clinical expression of only 58.99%, which has been suggested to be clinically relevant.[30,31] Despite this, it should be noted that substantial individual variation was observed, ranging from an underexpression of 17.6° to an overexpression of 8.6°.

In contrast, when the lingual movement of the mandibular incisors was planned, there was no significant difference between the predicted and achieved inclination changes. Other studies have reported similar findings.[28,32] However, Haouili et al[12] found both labial and lingual tooth movements resulted in shortfalls of 53%-64%, depending on the type of incisor moved and the direction of planned tooth movement.

It has been previously reported that tooth movement with CAT can occur in the opposite direction to the planned movement.[32-34] A similar issue was also noted in this study, with 48 of 249 incisors (19.3%) found to have moved in the opposite direction to the planned movement. At the separation of this data with respect to direction, it was found that 39 of 175 incisors (22.3%) digitally planned to have a labial movement expressed lingual movement instead. Furthermore, 9 of 74 incisors (12.2%) specifically intended to have lingual movement actually demonstrated labial movement. It may be considered that tooth movements which occur in the opposite direction to the digital prediction are highly unfavorable and may even be associated with iatrogenic damage in certain situations. This aspect of CAT most certainly requires further investigation.

With respect to predicted and achieved overjet changes, the results of this study demonstrated that Invisalign CAT underexpressed the predicted overjet changes, especially when a reduction in overjet was planned. This finding is consistent with the study by Meade and Weir.[35]

Similar to the labiolingual inclination changes, the difference between the predicted and achieved overbite

Table II. Predicted and achieved labiolingual inclination, overjet, and overbite

Variables	*Mean predicted movement (SD)*	*Mean achieved movement (SD)*	*Mean difference (95% CI)*	*Accuracy, %*	*t value*	P *value*
Labiolingual inclination change planned (°)						<0.001
Positive (n = 175)	7. 90 (6.18)	4.66 (5.80)	−3.24 (−4.29 to −2.18)	58.99	−6.0408	
Negative (n = 74)	−4.70 (3.91)	−4.25 (4.79)	0.45 (−0.91 to 1.82)	90.43	0.6656	
Overjet change planned (mm)						<0.001
Positive (n = 34)	1.54 (1.70)	1.17 (1.37)	−0.37 (−0.74 to 0.01)	75.97	−1.9722	
Negative (n = 52)	−1.39 (1.71)	−0.69 (1.45)	0.70 (0.29-1.04)	49.64	3.5590	
Overbite change planned (mm)						<0.001
Positive (n = 25)	1.00 (0.812)	0.90 (1.06)	−0.10 (−0.49 to 0.28)	90.00	−0.5526	
Negative (n = 61)	−2.12 (1.79)	−1.07 (1.44)	1.05 (0.73-1.38)	50.47	6.4800	

SD, standard deviation; *CI,* confidence interval.

Table III. Linear regression for predicted overjet and overbite changes

Coefficient	*Estimate*	*SE*	*t value*	*Pr (>|t|)*
Positive predicted overjet changes				
Intercept	−0.73	1.11	−0.66	0.52
Sex (male)	0.31	0.44	0.7	0.49
Age	−0.01	0.01	−0.78	0.44
2-wk protocol	2.37	1.35	1.75	0.09
No. of aligners (1-wk protocol)	0.02	0.02	0.84	0.41
No. of aligners (2-wk protocol)	−0.07	0.04	−1.86	0.07
Negative predicted overjet changes				
Intercept	0.57	1.34	0.43	0.67
Sex (male)	−0.29	0.42	−0.7	0.49
Age	−0.03	0.01	−2.22	0.03*
2-wk protocol	1.53	1.64	0.93	0.36
No. of aligners (1-wk protocol)	0.03	0.03	0.98	0.33
No. of aligners (2-wk protocol)	−0.04	0.04	−0.87	0.39
Positive predicted overbite changes				
Intercept	0.76	1.25	0.61	0.55
Sex (male)	0.15	0.47	0.31	0.76
Age	0.01	0.02	0.41	0.69
2-wk protocol	−0.52	1.39	−0.37	0.72
No. of aligners (1-wk protocol)	−0.03	0.02	−1.58	0.13
No. of aligners (2-wk protocol)	0.02	0.04	0.40	0.70
Negative predicted overbite changes				
Intercept	0.26	1.07	0.24	0.81
Sex (male)	−0.32	0.35	−0.92	0.36
Age	0.01	0.01	0.8	0.43
2-week protocol	0.73	1.34	0.55	0.59
No. of aligners (1-wk protocol)	0.01	0.02	0.34	0.74
No. of aligners (2-wk protocol)	−0.01	0.04	−0.22	0.83

SE, standard error; *Pr(>|t|)*, the *P* value associated with the value in the t value column.
**P* <0.05.

changes varied depending on the direction of the planned change. When an increase in the overbite dimension was planned, the Invisalign appliance expressed 90% of these planned changes, with no significant difference found between the predicted and achieved overbite changes. This finding differs from a recent study by Meade and Weir,[35] which found that Invisalign CAT overexpressed the planned overbite increase, in which the mean overbite expression was 108.7%. Further analysis of the extraction subgroup revealed that 222.7% of the predicted overbite increase was achieved.[35] In contrast, Blundell et al[36] examined a sample of patients with open bite that were treated without extractions and found that Invisalign CAT underexpressed overbite changes, with a mean expression of 66.2% of the planned overbite increase. The

Table IV. Linear regression for predicted labiolingual changes

Coefficient	*Estimate*	*SE*	*t value*	*Pr (>|t|)*
Positive predicted labiolingual changes				
Intercept	−0.95	3.21	−0.3	0.77
Sex (male)	−1.55	1.20	−1.29	0.20
Age	0.05	0.04	1.16	0.25
2-wk protocol	−3.88	3.67	−1.06	0.29
No. of aligners (1-wk protocol)	−0.08	0.06	−1.29	0.20
No. of aligners (2-wk protocol)	0.08	0.10	0.77	0.45
Negative predicted labiolingual changes				
Intercept	−5.39	6.66	−0.81	0.42
Sex (male)	0.97	1.90	0.51	0.61
Age	−0.05	0.03	−1.38	0.17
2-wk protocol	10.39	6.57	1.58	0.12
No. of aligners (1-wk protocol)	0.23	0.22	1.04	0.30
No. of aligners (2-wk protocol)	−0.36	0.21	−1.69	0.10

SE, standard error; *Pr(>|t|)*, the *P* value associated with the value in the t value column.

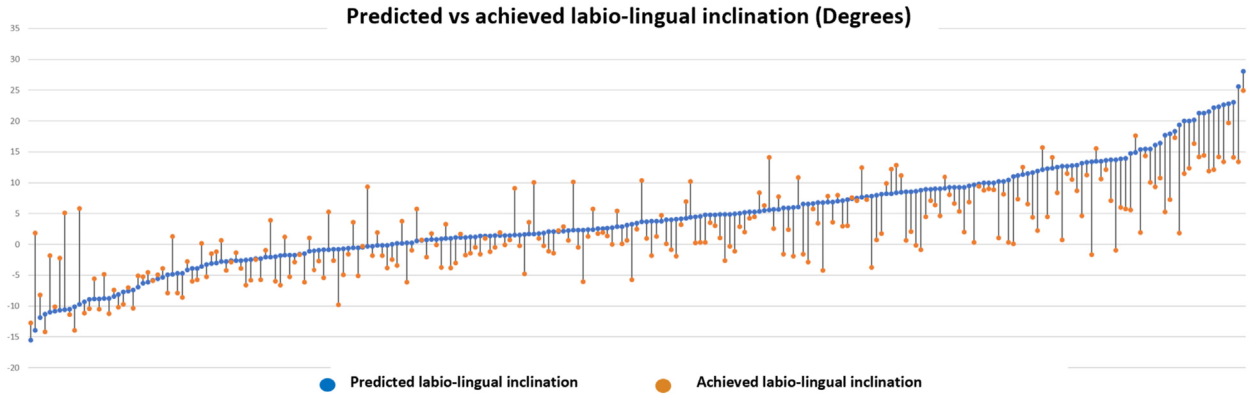

Fig 6. Predicted labial-lingual inclination movement values vs achieved angular labiolingual inclination movement values.

seemingly conflicting results of these studies may be largely attributed to the difference between the respective samples investigated. Extraction of teeth is considered to have a tendency to deepen the bite through incisor retroclination and mesial movement of the molars.[5] However, the latter effect of mesial molar movement has been strongly contested.[37]

The tendency for CAT to result in underexpression of labial crown inclination and overexpression of lingual crown inclination in the mandibular incisors has been noted in the literature.[28] A finite element study of mandibular incisors by Li et al[38] noted that, with the intrusion of mandibular incisors, the center of resistance was always subjected to force toward the lingual and intrusively, resulting in the mandibular incisor roots always tipping labially.

In this study, when the specific treatment objective was to decrease the overbite dimension, 50.5% of the predicted overbite decrease was clinically achieved. This finding corroborates with other studies that found an expression of 33.0%-44.7% when nonextraction anterior bite opening mechanics were used for CAT.[30,39-41] Meade and Weir[35] compared patients with extraction and nonextraction and found that CAT, which involved extraction of premolar teeth, had significantly less overbite reduction (ie, 8.7% overbite reduction) than nonextraction protocols (45.8% overbite reduction). Although the extraction pattern in this study is different, it appears that decreasing the overbite dimension for any extraction pattern with CAT is more likely to be challenging.

The results of the labiolingual inclination changes appear to corroborate the findings of the overbite changes. The shortfall in labial tooth movement expression may have contributed to the shortfall in the deepbite correction. Galan-Lopez et al[41] reported that overbite reduction for patients with deepbite was primarily achieved through mandibular incisor proclination; therefore, a lack of achieved proclination would reduce the effectiveness of the overall deepbite correction. This study found that the clinical expression of planned mandibular incisor retroclination was not problematic, which appears to support the adequacy of bite closure with CAT.

The duration of wear per aligner, total treatment duration, age, and gender did not significantly influence the predictability of the clinical expression of tooth movements that were assessed apart from when a decrease in overjet was planned. The aligner wear schedule (1 week vs 2 weeks) has not been shown to significantly affect the labiolingual inclinations of anterior teeth.[30,32,42] Despite this finding, other types of movements and other teeth may benefit from a 2-weekly wear protocol compared with a 7-day or 10-day protocol.[30,43] The type and presence of attachments were not found to be associated with the development of an OGE. However, it has been postulated that attachments might improve the root parallelism of the incisors and, thus, decrease the likelihood of developing an OGE. Smith et al[33] found that attachments made no significant improvement in the expression of the mesiodistal tip of the mandibular incisors. Interestingly, Zhang et al[44] found that attachments were positively correlated with the prevalence of OGEs; however, no significant relationship was detected with respect to the severity of these OGEs.[44] The sample used in this study was investigated for mesiodistal mandibular incisor angulation by Truong et al,[19] who reported good efficacy (78.9%) in clinically achieving the planned angulations.

The potential clinical relevance of this study stems from the quality of the data which was analyzed. A total of 17 experienced orthodontists contributed to the database of previously treated patients, which resulted in a relatively large sample of patients with mandibular incisor extraction (n = 83). In addition, the digital measurements of overbite, overjet, and labiolingual inclination changes were recorded using objective measurement software, which removes human-related measurement errors.

The results of this study indicate that clinicians should be aware of the potential shortfalls in planned movements, especially mandibular incisor labiolingual inclination and overbite reduction, and be prepared to address these with either overmovement of identified shortfalls in the digital treatment plan or else the likely need for additional aligners. The high prevalence of OGEs posttreatment is something clinicians should be aware of. As this study and Truong et al[19] were unable to identify specific causes, further investigation is warranted.

The limitations of this study are acknowledged. The retrospective nature of this study carries a risk of selection bias. This risk of selection bias was addressed by requiring the contributing clinicians to submit every treated patient to the database, irrespective of the quality of the treatment outcome achieved. This mandatory requirement prevents the omission of any suitable patients and also results in a large final sample for analysis. In addition, strict inclusion and exclusion criteria were applied to eligible patients included in this study. Another limitation of the study is that all assessments that were made were related to the initial series of aligners only, which does not necessarily mean the orthodontic treatment has been completed. It is generally accepted that most patients would benefit from further orthodontic refinement beyond the initial series of aligners.[45-47] Despite this limitation, this study provides useful information regarding the initial efficacy for tooth movements after extraction of a single mandibular incisor. Similar to other studies, the measurements in this study did not distinguish between root or crown inclination changes.[28,30,48] Without radiologic or cone-beam computed tomography (CBCT) data, it is not possible to calculate the exact contributions of the root and crown movements to the labiolingual inclination changes. Obtaining routine pretreatment, progress and posttreatment CBCT data is difficult to justify from a radiation hygiene perspective. In addition, neither CBCT nor other radiographic data have a predicted outcome to be analyzed, making efficacy assessment impossible. To address this lack of radiologic data, previous studies have used averages for root lengths and calculated theoretical centers of rotation.[32,33] Because of the characteristics of the sample analyzed, the results of this study are specific to Invisalign CAT of adult patients treated with extraction of a single mandibular incisor. Therefore, extrapolation and application of this particular study's results to other patient groups and proprietary clear aligners may not be possible. The final limitation is that digital superimposition on stable structures was not possible in this study. The recording and use of stable structures such as the palatal rugae or titanium implants would greatly facilitate any superimposition. Unfortunately, no such stable structures have been described in the literature for the mandibular arch in the context of digital casts. Despite this, the method of best-fit superimposition has been used extensively and can be viewed as the best current method for studies investigating the mandibular arch.[28,33,40] Meade and Weir[49] have demonstrated that best-fit superimposition with Geomagic Control X is highly accurate in systems involving Newtonian movements such as those in this study.

CONCLUSIONS

When using Invisalign to treat patients involving a mandibular incisor extraction:

1. ClinCheck overestimated the clinical expression with respect to proclination of incisors, overjet changes, and overbite reduction.
2. With respect to the planned proclination of the mandibular incisors, only 59.0% was clinically expressed.
3. When a decrease in overjet was planned, only 49.6% of the predicted overjet changes were clinically expressed. In contrast, when an increase in overjet was planned, 76.0% of the predicted change was expressed.
4. Only 50.5% of the planned overbite reduction was clinically expressed.
5. In 95.2% of patients, an OGE was evident at the site of the previously extracted mandibular incisor when the initial treatment series of aligners was completed.

AUTHOR CREDIT STATEMENT

Keith Chan contributed to conceptualization, formal analysis, investigation, methodology, project administration, validation, visualization, original draft preparation, and manuscript review and editing; Tony Weir contributed to conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, supervision, validation, visualization, and manuscript review and editing; Elissa Freer contributed to conceptualization, resources, supervision, and manuscript review and editing; Desmond Ong contributed to conceptualization, resources, supervision, and manuscript review and editing; and Hien Nguyen contributed to formal analysis and manuscript review and editing.

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