Original Article

The predictability of maxillary curve of Spee leveling with the Invisalign appliance

Zi Wei Lim[a]; Maurice J. Meade[b]; Tony Weir[c]

ABSTRACT

Objectives: To evaluate the predictability of the Invisalign appliance (Align Technology, Santa Clara, Calif) in leveling the maxillary curve of Spee (COS).

Materials and Methods: A retrospective sample of adult subjects treated with the Invisalign appliance between 2013 and 2019 were selected. Patients were treated nonextraction in the maxillary arch and had either Angle Class I or II malocclusions with a minimum of 14 aligners with no bite ramps. Initial, predicted, and actual outcomes were analyzed with Geomagic Control X software (version 2017.0.3; 3D Systems, Cary, NC).

Results: A sample of 53 cases satisfied inclusion/exclusion criteria. Paired *t*-tests demonstrated a significant difference between mean predicted and actual maxillary COS leveling with a shortfall of 0.11 mm (SD = 0.37; $P = .033$). Planned intrusion tended to be more accurate posteriorly with an overexpression of 117% for the first molars. Planned extrusion was the least accurate, with the mid-arch demonstrating expressions of −14% to −48%. These teeth intruded despite a prescribed extrusive movement.

Conclusions: The Invisalign appliance did not accurately predict maxillary COS leveling. Planned intrusive movements were overcorrected, and planned extrusive movements were either undercorrected or resulted in intrusion. This effect was most apparent for the upper first molar, which expressed 117% and −48% of planned intrusion and extrusion, respectively. (*Angle Orthod.* 2023;93:638–643.)

KEY WORDS: Occlusal plane; Maxilla; Invisalign; Aligner

INTRODUCTION

The use of the Invisalign appliance involves virtual treatment-planning software (ClinCheck) to enable communication between Align Technology and the clinician.[1] ClinCheck provides the tools to prescribe interproximal reduction (IPR), bonded composite resin attachments, altered aligner geometries such as bite ramps, power ridges, and “cutouts” for intermaxillary elastics, which aim to aid in more predictable tooth movement.[2,3]

One of the current shortcomings of the Invisalign system is its relatively poor ability to predict the appliance’s affect on vertical issues.[4] While many claim that clear aligner therapy (CAT) appears to have difficulty in managing deep overbite cases,[3,5,6] other researchers dispute this.[7–9] Management of such issues usually relies on an ability to intrude or extrude the appropriate anterior and posterior teeth predictably to level the occlusal planes of both upper and lower dental arches.[3,5] This has been shown to be challenging with aligners.[10]

Leveling the occlusal planes has long been considered an essential objective in comprehensive orthodontic treatment to achieve good intercuspation of teeth.[11] While the lower arch is most commonly referred to when referencing the curve of Spee (COS), both arches contribute to the final occlusal table. A recent

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Table 1. Selection Criteria

Inclusion Criteria	
	≥18 y old pretreatment
	≥14 aligners
	2-wk full-time wear per aligner
	Class I or II Angle malocclusion
	Mild-moderate crowding
	Full permanent dentition including second molars
	Nonextraction upper arch
	Treatment between 2013 and 2019 (SmartTrack material)
	Upper and lower arch treatment
Exclusion Criteria	
	Noncompliant or nonattenders
	Intermaxillary elastics
	Bite ramps
	Combined orthognathic surgery or orthodontic treatment
	Previous orthodontic treatment
	Incomplete registration of mesiobuccal cusp of second molar
	Craniofacial disorders
	Medical conditions affecting bone metabolism or tooth movement

study indicated that the Invisalign appliance was not effective in leveling the mandibular COS.[12] However, no studies have investigated this for the maxilla.

Therefore, this study aimed to investigate the accuracy and characteristics of maxillary COS leveling in comparison with the digital treatment prediction. The null hypothesis was that there would be no difference between the predicted ClinCheck and actual clinical maxillary COS leveling.

MATERIALS AND METHODS

Ethical approval was obtained from the University of Adelaide Human Research Ethics Review Group (No. H-2021-155). The subjects were obtained from an independent database of approximately 12,000 patients treated in multiple specialist private practices with the Invisalign appliance. The total database was assessed, and the selection criteria (Table 1) resulted in a significant reduction in appropriate cases. All cases that met the criteria were selected. The cases were treated by orthodontists in three different countries. Specialists had at least 10 years of experience with CAT and had treated at least 300 cases each. Records were subsequently de-identified. Three-dimensional stereolithographic (STL) models of each subject were obtained at three time points: the initial pretreatment intraoral scan (T_1), the predicted ClinCheck result (T_2), and the scan after the initial series of aligners (T_3). This allowed the study to focus solely on evaluating the predictability of an initial series of aligners and determine the level of agreement between the predicted values and the actual outcomes.

The sample size used in this study was based on a similar study by Goh et al.,[12] which investigated the COS in the mandible. They found an estimated power of 92.6% with a sample of 10 subjects.[12] Ultimately, 53 subjects met the criteria, which was greater than the 42 subjects found in the previous study.

The ClinChecks were programmed by the treating clinician to achieve the optimal clinical outcome; overcorrection was prescribed where it was considered appropriate. Nonprescribed IPR was not performed. Both conventional and optimized attachments were used where deemed appropriate. Default auxiliaries were accepted where it was deemed appropriate. Align default COS leveling attachments were never removed, and, in some instances, clinicians augmented these with conventional attachments.

STL files were imported into Geomagic Control X software (version 2017.0.3; 3D Systems, Cary, NC). A reference plane as used by Blundell et al.[10] was applied to the initial (T_1) model only.[10] The subsequent models were superimposed on the T_1 model separately using an automatic best fit registration with global and fine best fit, maximum point iteration of 50, and 80% sampling ratio. The vertical positions of the occlusal surfaces of the dentition were determined by a perpendicular linear distance from the reference plane to the cusp tips of the canines, buccal cusp tips of the premolars, and mesiobuccal cusp tips of the first and second molars (Figure 1). These positions were subsequently used to analyze the relative changes that occurred. The COS depth was calculated as the difference between the cusp tips with the most and least linear distance to the reference plane on the same model.

Intraexaminer error was measured by repeating the landmarking on 10 randomly selected cases after a period of at least 2 weeks as per Goh et al.[12]

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (version 27.0.0.0; SPSS Inc., Chicago, Ill).

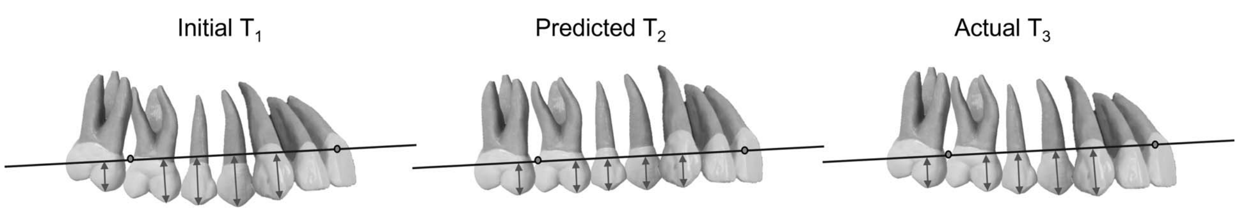

Figure 1. Diagram illustrating the perpendicular linear measurements for each time point.

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Table 2. Demographics and Treatment Duration[a]

Variable	Descriptive Statistics	*P* Value
Age at start of treatment, mean (SD), y	M 31.8 (11.6)	*t*-test $P = .769$
	F 33.5 (10.9)	
	Total 33.0 (11.0)	
Sex, n (%)	M 16 (30.2)	χ^2 $P = .004$*
	F 37 (69.8)	
	Total 53 (100)	
Treatment duration, mean (SD), mo	M 10.9 (3.4)	*t*-test $P = .708$
	F 10.7 (3.3)	
Age categories, y	n (%)	
18–25	16 (30.2)	χ^2 $P = .783$
26–35	20 (37.7)	
36+	17 (32.1)	

[a] F indicates female; M, male.
* $P < .05$.

Intraexaminer reliability was determined by intraclass correlation coefficients (ICCs) from repeated measurements. The Shapiro-Wilk test for normality was performed for the initial COS depth, the actual change (T_3-T_1), and the predicted ClinCheck change (T_2-T_1). Paired-samples *t*-tests were used to compare the actual change to the predicted ClinCheck change. Chi-square tests (χ^2) were used to compare the proportion of males to females as well as between age groups. The level of significance was set at $P < .05$.

RESULTS

A total sample of 53 subjects met the inclusion criteria for this study. There were no significant differences between the age at initial treatment, nor treatment duration, with respect to sex (Table 2). There were significantly more female patients than males ($P < .004$). The Shapiro-Wilk tests indicated that the data were normally distributed. ICC was calculated to be between .95 and .99. Twenty-five patients had planned IPR, 10 of whom had an average of 1.42 mm prescribed posteriorly. Spaced cases were not included.

Table 3 represents the COS changes. Most cases presented with an initial COS depth of 1–3 mm. The difference between predicted and actual movements was only significant overall.

Table 4 and Figure 2 demonstrate cases analyzed with respect to the direction of planned tooth movement. No significant difference was found between the predicted and actual movements of the molars and the second premolars when an intrusive movement was planned. Within the planned intrusion subgroup, there was a mean (SD) shortfall of 0.12 mm (0.36) and 0.28 mm (0.37), respectively, for the first premolars and canines, which was significant ($P = .013$, $P < .0001$). The amount of expression appears to have been greatest for the first molars with a decreasing trend anteriorly.

There were significant differences between all predicted and actual movements within the planned extrusion subgroup ($P < .0001$). The shortfall was between 0.29 mm (0.24) and 0.4 mm (0.22). The mean expression for the first molars and premolars demonstrated an intrusive movement despite extrusion being planned. The second molars and canines demonstrated minimal expression of planned intrusion of 8% and 36%, respectively.

DISCUSSION

This study was the first to investigate the predictability of leveling the maxillary COS with the Invisalign appliance. While bite ramps or intermaxillary elastics are frequently used to assist with vertical control, this study sought to examine the inherent capacity of Invisalign to manage maxillary vertical movements without the use of such auxiliaries, in cases treated by experienced Invisalign providers. Building on previous research,[10] future studies could explore the efficacy of these auxiliaries and compare their individual influence, distinct from Invisalign's innate abilities. The selection criteria were applied to identify a sample of patients who would reasonably be encountered in routine orthodontic practice in which the Invisalign

Table 3. Mean Curve of Spee (COS) Leveling[a]

Initial COS Depth	n (% of Total)	Initial Mean COS[b] (SD)	Predicted Mean COS[b] (SD)	Actual Mean COS[b] (SD)	Mean CC (SD)	Mean AC (SD)	Mean AC-CC (SD)	Expression, AC/CC, %	P-value AC vs CC
Total	53 (100)	2.57 (0.96)	2.32 (1.00)	2.43 (0.96)	0.25 (0.47)	0.14 (0.37)	0.11 (0.37)	55	.033*
1–2 mm	16 (30.2)	1.53 (0.32)	1.44 (0.48)	1.49 (0.48)	0.09 (0.43)	0.03 (0.39)	−0.06 (0.30)	33	.457
2–3 mm	22 (41.5)	2.49 (0.27)	2.21 (0.62)	2.35 (0.31)	0.28 (0.52)	0.14 (0.31)	−0.15 (0.47)	50	.159
3–4 mm	11 (20.8)	3.55 (0.31)	3.10 (0.50)	3.21 (0.59)	0.45 (0.41)	0.33 (0.45)	−0.12 (0.29)	73	.212
>4 mm	4 (7.5)	4.49 (0.70)	4.36 (0.69)	4.48 (0.58)	0.13 (0.22)	0.02 (0.20)	−0.12 (0.25)	15	.421

[a] All measurements are in millimeters unless otherwise stated. AC indicates actual change; CC, ClinCheck change.
[b] COS was measured by the difference between the cusp farthest away from reference plane to the cusp closest to the reference plane. Left and right sides were then averaged to find the mean. A positive linear change indicates an intrusive movement. A negative linear value indicates an extrusive movement.
* $P < .05$.

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Table 4. Mean Vertical Movement of Teeth Relative to the Reference Plane by Planned Movement[a]

Movement Planned	Tooth (n)	Mean Initial (SD)	Mean CC (SD)	Mean AC (SD)	Mean AC-CC (SD)	Expression, AC/CC, %[b]	*P* Value AC vs CC
Planned intrusion	M2 (52)	2.81 (0.85)	0.17 (0.21)	0.15 (0.33)	−0.02 (0.32)	88	.671
	M1 (56)	4.19 (0.75)	0.23 (0.24)	0.27 (0.22)	0.03 (0.27)	117	.351
	PM2 (70)	5.02 (0.82)	0.36 (0.32)	0.35 (0.26)	−0.01 (0.36)	97	.834
	PM1 (61)	5.23 (0.94)	0.38 (0.33)	0.26 (0.29)	−0.12 (0.36)	68	.013*
	C (50)	5.47 (1.07)	0.54 (0.40)	0.26 (0.29)	−0.28 (0.37)	48	.000*
Planned extrusion	M2 (54)	2.62 (0.88)	−0.36 (0.39)	−0.03 (0.26)	0.34 (0.38)	8	.000*
	M1 (50)	3.71 (0.74)	−0.23 (0.22)	0.11 (0.21)	0.34 (0.29)	−48	.000*
	PM2 (36)	4.26 (0.94)	−0.35 (0.35)	0.05 (0.28)	0.40 (0.22)	−14	.000*
	PM1 (45)	4.69 (1.07)	−0.24 (0.26)	0.05 (0.22)	0.29 (0.24)	−21	.000*
	C (56)	4.39 (1.13)	−0.50 (0.39)	−0.18 (0.27)	0.32 (0.40)	36	.000*

[a] All measurements are in millimeters unless otherwise stated. A positive linear change indicates an intrusive movement. A negative linear value indicates an extrusive movement. AC indicates actual change; B, buccal; C, canine; CC ClinCheck change; M1, first molar; M2, second molar; MB, mesiobuccal; PM1, first premolar; PM2, second premolar.

[b] A negative expression percentage indicates an actual vertical movement that occurred was opposite to the prescribed direction.

* $P < .05$.

appliance might be used. There was a greater proportion of female patients in this study, which correlated well with the demographic of patients treated with CAT.[4,5,12,13] The sample size of 53 was also greater than that reported in similar studies.[4,5,12,13]

The occlusion of both maxillary and mandibular segments influences the eventual overbite of a patient. However, the planned maxillary tooth position is often determined in the context of a patient's smile.[14] Therefore, these teeth may not have been necessarily planned to be level with the maxillary COS. This may explain why there was an almost equal distribution of planned intrusive and extrusive movements for any given tooth. This differs from that in the mandibular arch, where planned movements of the mid-arch region are primarily extrusive.[12] Although the treatment objectives may vary for each arch, the primary focus of this study was to evaluate the clinical manifestation of prescribed maxillary movements rather than the objectives themselves. The results suggested that the clinician's treatment plan failed to achieve the desired changes and is therefore a possible contributing factor to Invisalign's limited capacity to manage the overbite.

The mean maxillary COS depth was 2.57 mm in this study. This was greater than the 1.6 mm reported by Xu et al.[15] Individuals with a Class II molar relationship tend to have an increase in COS, and the inclusion of such cases here may help explain this difference.[16] The mean age of individuals studied by Xu et al.[15] was 21 years, compared with 33.0 years in the current study.

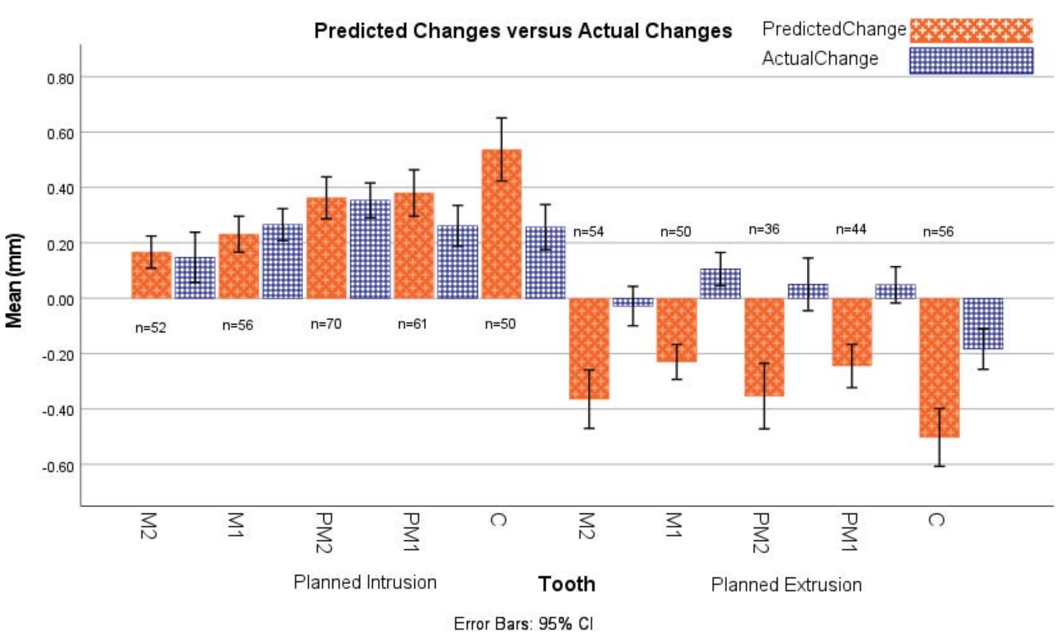

Figure 2. Vertical movement of teeth relative to the reference plane by planned movement. C indicates canine; M1 first molar; M2, second molar; PM1, first premolar; PM2, second premolar.

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Therefore, factors such as late facial growth,[11,17] occlusal wear,[18] and occlusal forces,[17] could have increased the initial maxillary COS at presentation in this study.

ClinCheck has been shown to have a mean COS leveling accuracy of 35% in the mandibular arch.[12] The present study found that ClinCheck underestimated COS leveling in the maxillary arch by 46%. Shallower maxillary COS depths demonstrated increased expression.

To approach Invisalign as a force-directed system rather than just a representation of the final outcome, the term *expression* was used instead of *accuracy*. This permits for percentage variations that go beyond 100 or fall below zero. Such data can better inform the clinician of the direction and magnitude of the shortfalls, allowing them to take appropriate corrective measures. Prescribed intrusion expression appeared to increase toward the posterior teeth and peaked at the first molar (117%). All teeth that had planned extrusion significantly underexpressed the amount of extrusion predicted in ClinCheck. Interestingly, the mean expressions of movement for the mid-arch region demonstrated a range of expression between −14% and −48%, indicating that these teeth intruded despite extrusive movements being prescribed. These findings mirror those of Goh et al.,[12] who found poor extrusion of posterior mandibular teeth with an accuracy between 31% and 52%.

Several researchers have speculated that CAT may have an intrusive effect on posterior teeth.[3,6,7] This has been suggested to be due to the "bite block" effect from the thickness of aligners.[6] Talens-Cogollos et al.[19] found that 41.4% of intrusion occurred in the maxillary molar with CAT using cephalometric analysis. They reported a negative correlation between mandibular and occlusal plane angles with maxillary molar intrusion, which they speculated was related to masseteric muscle activity. This intrusion appeared to be self-limiting to ∼1 mm in both molars. Interestingly, a cephalometric study by Rask et al.[20] found CAT did not demonstrate this effect when no vertical molar movements were planned. Caution, however, should be applied when interpreting these findings due to possible cephalometric measurement error.

CAT tends to expand maxillary arches primarily by tipping rather than bodily movement.[13] A buccal tip of these teeth would lead to a perception of relative intrusion. It is, therefore, possible that this finding of an "intrusive" effect and creation of a posterior open bite may be partly related to a lack of ability for CAT to torque posterior teeth.

The second molars did not appear to intrude as much as the first molars did. This may have been related to the amount of buccal tip that was expressed. Haouili et al.[5] found the accuracy of the buccal tip of the second molars (34.8%) to be much less than that of the first molar (58.3%) and second and first premolars (60.5%, 66.3%).

The lack of extrusive ability may be related to the physical shape of the teeth themselves. The further posterior the tooth, the shorter the clinical crown height and, therefore, undercuts available for the appliance to be able to effectively apply a force in the intended direction.[5]

Further research is needed to identify the amount of maxillary torque expression in this data set to determine the contribution the buccal tip may play with the observed intrusion in this study. It also is possible that some of the intrusive changes found, despite planned extrusion, were due to a reciprocal effect of relatively greater extrusion planned for other teeth in the arch. Nevertheless, it raises the question why such a phenomenon was not also observed with teeth that had planned intrusion.

This study was retrospective in nature and therefore had inherent limitations. Because all cases from the database that met the criteria were included, selection bias was minimized. The strict selection criteria aimed to eliminate confounders to enable effective evaluation of the ability of the Invisalign appliance itself. This resulted in cases that were limited to "mild" to "moderate" overbite cases. Ten patients had IPR prescribed posteriorly in the study presented here. However, this was likely to have a minimal effect as, on average, 50%–56% of planned IPR is not performed in vivo by most clinicians.[21] Although the study assessed both Class I and Class II cases together, a subgroup analysis was not conducted due to the limited number of patients involved. As a result, this study could provide a foundation for future research exploring the effect of CAT among different malocclusions.

While the initial overbite presented here may not be considered challenging, such cases are representative of the average CAT patient and, hence, more clinically applicable. If the Invisalign appliance struggled to achieve modest outcomes, it may be reasonable to assume that deeper overbites may be more challenging. This was further compounded by the inclusion of attachments in this study. The use of attachments may aid in extrusive movements and provide better torque control to reduce any relative intrusion of posterior teeth. Such an inclusion only serves to further validate the findings of this study as one would expect less predictability without them. The relatively small number of patients with attachments precluded a subgroup analysis. As such, this may be an area for future research. It may also be reasonable to believe that full leveling of the maxillary arch of patients is unlikely to occur within a 10- to 11-month period. However, the

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goal of this article was to determine the nature of any inadequacies so that future studies may attempt to provide more robust evidence on their management.

The study's clinical findings indicated that attempting to open a bite or level the upper COS through upper molar extrusion with CAT may not produce the desired outcome and may even worsen the bite. As a result, clinicians may wish to explore other options or appliances to achieve their objectives. The predictability of Invisalign in posterior vertical movements has received limited research attention, resulting in a lack of literature on how to address these concerns. Nevertheless, clinicians may therefore seek to prescribe overcorrection or use anterior bite ramps or intermaxillary elastics to overcome the apparent limitation of posterior extrusion with CAT.[22] Alternatively, there was some indication that posterior intrusion may be a more dependable technique for achieving leveling with CAT.

CONCLUSIONS

- The Invisalign appliance did not accurately predict maxillary COS leveling.
- There was a tendency for an increase in intrusive movements posteriorly regardless of whether intrusion or extrusion was planned.
- This effect was most apparent with the upper first molar, which expressed 117% and −48% of planned intrusion and extrusion, respectively.
- The use of auxiliaries or prescription of overcorrection should be considered within ClinCheck when planning upper posterior extrusion with the Invisalign appliance.

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