Original Article

Occlusal contacts and treatment with the Invisalign appliance: a retrospective analysis of predicted vs achieved outcomes

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ABSTRACT

Objectives: To quantify the predicted occlusal contact outcomes compared with the clinically achieved occlusal contacts following treatment using the Invisalign aligner appliance.

Materials and Methods: The occlusal contacts of 33 adult patients presenting with a Class I mild-to-moderate malocclusion (spacing <4 mm or crowding of <6 mm) and treated using the Invisalign appliance were measured at the initial, predicted, and achieved stages of treatment by the metrology software Geomagic Control X. Assessed measurements were related to individual teeth and anterior, posterior, and overall contacts.

Results: The mean (standard deviation) difference between the achieved occlusal contact was significantly less than that predicted for overall occlusal contact and posterior occlusal contact ($P < .0025$). The achieved posterior occlusal contact was also less than pretreatment initial posterior occlusal contact. There was no difference in anterior occlusal contact between the predicted and achieved outcomes ($P > .05$). The central and lateral incisors displayed no statistically significant difference between the predicted and achieved occlusal contact. The patients with prescribed overcorrection demonstrated a statistically significant difference in predicted occlusal contact compared with those with nonprescribed overcorrection ($P \leq .0025$), but no statistically significant difference in achieved occlusal contact.

Conclusions: Treatment by the Invisalign appliance in Class I mild-to-moderate malocclusion resulted in a decrease in posterior occlusal contact. Further research is required to account for the deficiencies between the predicted and achieved clinical outcome related to occlusal contact and to determine the corrective changes required in the treatment protocols. (*Angle Orthod.* 2023;93:275–281.)

KEY WORDS: Clear aligner therapy; Invisalign; Occlusal outcome; Orthodontic treatment outcome

INTRODUCTION

Clear aligner therapy (CAT) is now an established orthodontic treatment modality.[1] It uses proprietary software to predict and stage the tooth movement across a sequence of aligners. Invisalign (Align Technology, San Jose, Calif) is a leading CAT manufacturer and provides clinicians with a digital representation of the patient's predicted occlusal outcome as part of its treatment planning processes.[2]

A posterior occlusal open bite is a frequently reported complication of Invisalign treatment.[1,3,4] The suggested causes include the thickness of the aligner foil that prevents the ideal development of occlusal contact, a suboptimal bite opening, a loss of incisor torque, or a loss of buccal root torque associated with transverse expansion.[3,5,6] The provision of additional aligners (refinement) after the initial course of care, the use of auxiliaries, overcorrection, or the incorporation

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of heavy contact into the digital treatment plan have been proposed as methods to address the issue.[6]

The presence of a maximum number of occlusal contacts is closely correlated with and, is considered essential for, optimal masticatory function.[7,8] The American Board of Orthodontics (ABO) Objective Grading Scoring (OGS) is commonly used to assess the quality of end-of-treatment fixed appliance therapy (FAT) and CAT.[9] A 2005 study showed that the Invisalign appliance was deficient in obtaining maximum occlusal contact at the end of treatment.[10] Recent developments in metrology technology, however, have enabled a more sophisticated analysis of occlusal relationships.[3,11]

The aim of the present study, therefore, was to determine the presence of, and quantify, if appropriate, the differences between the predicted occlusal contact and the clinically achieved occlusal contact produced by the Invisalign appliance. The null hypothesis was that there would be no differences between the predicted occlusal contact and the clinically achieved occlusal contact produced by the Invisalign appliance.

MATERIALS AND METHODS

The sample was obtained from a database of approximately 7000 patients treated using the Invisalign appliance between 2013 and 2018 by orthodontists experienced in the use of the appliance. All participants provided valid consent for their complete records to be used for educational and research purposes prior to the commencement of treatment. Institutional ethical approval for the study was granted by the University of Adelaide Human Research Ethics Committee (33817).

Inclusion Criteria

- Patients aged $\geq$18 years
- Complete permanent dentition, excluding third molars
- Class I malocclusion with spacing $<$4 mm or crowding $<$6 mm
- Nonextraction treatment
- Orthodontic treatment exclusively using Invisalign (SmartTrack material) treated between 2013 and 2018
- Completion of the entire prescribed initial aligner sequence
- A 2-week aligner wear protocol
- Patient compliance with a "22 hour per day" appliance wear protocol (Compliance was assessed by the clinician via the clinical assessment of aligner fit and condition.)
- Digital models scanned intraorally using iTero scanners (Align Technology, San Jose, Calif) at the initial and achieved time points
- Digital models that had complete capture of the anatomy of the permanent dentition excluding the third molars at the initial and achieved time points

Exclusion Criteria

- Periodontally compromised patients
- Patients with initial "posterior open bites" and/or crossbites
- Orthognathic surgery cases
- Patients prescribed intermaxillary elastic use
- Patients who received restorative treatment to the teeth during orthodontic treatment
- Patients with a history of bone metabolism–altering medication

Based on the calculation of a 2015 study, a minimum sample size of 12 was determined necessary to detect a 0.5-mm difference between the predicted and achieved clinical outcomes.[12] An additional 21 participants were included for a total sample size of 33.

The measurements were carried out on the pretreatment and end of initial aligner sequence (achieved) digital models and the predicted outcome digital models from the Invisalign ClinCheck software facility via stereolithographic (.STL) files.

The .STL files were entered into Geomagic Control X (3D Systems, Rock Hill, S.C.) metrology software, which has been validated for evaluating CAT effects.[13,14] The mesh deviation tool was used with a maximum deviation of 5 mm to measure the precise "nearest neighbor" distances between the vertices and mesh faces of any point between the opposing arches. A distance heatmap was created with thresholds in 0.1-mm increments and a range of –1.0 mm to 1.0 mm (Figure 1). Occlusal contact was viewed on Geomagic Control X as a negative mesh deviation ($\leq$0.00 mm), that is, overlap, but recorded as a positive number. Occlusal clearance was defined as a positive mesh deviation ($>$0.00 mm) but recorded as a negative measurement. Contact was recorded as the greatest mesh deviation in a negative direction. The posterior teeth were divided mesiodistally and had recorded contact for separate buccal and palatal surfaces. The anterior teeth were recorded as a single contact per tooth. The contact measurements were recorded at the initial, predicted, and at the end of the initial aligner sequence (achieved) time points and pertained to teeth in the maxilla. Each data set was tested for normality by applying the Shapiro-Wilks test. The study sample was divided into normal (n = 20) and overcorrection (n = 13) occlusal contact groups. Overcorrection was defined as having $\leq$–0.25 mm mesh deviation for at least four teeth on the digital model (Figure 2). The

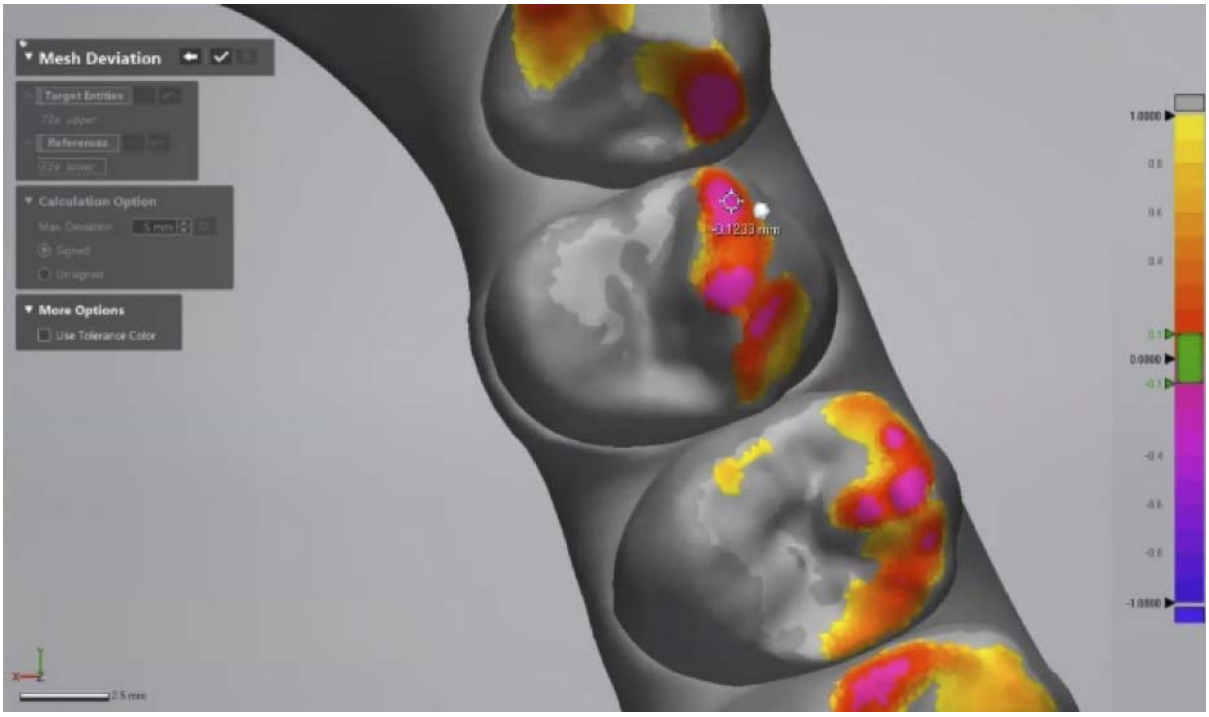

Figure 1. Recording of the greatest mesh deviation.

difference between the predicted and achieved occlusal contact measurements were analyzed for both groups. Demographic details regarding the patient's age, sex, and initial treatment-related parameters were documented. The mean and standard deviation (SD) values were calculated for the absolute initial, predicted, and achieved occlusal contact measurements and related to the mean values between individual teeth and their antimeres.

All data sets contained variables with a normal distribution. A paired-sample *t*-test was used to assess the difference between the absolute and mean changes of the predicted and achieved occlusal contact for overall, anterior, posterior, and individual

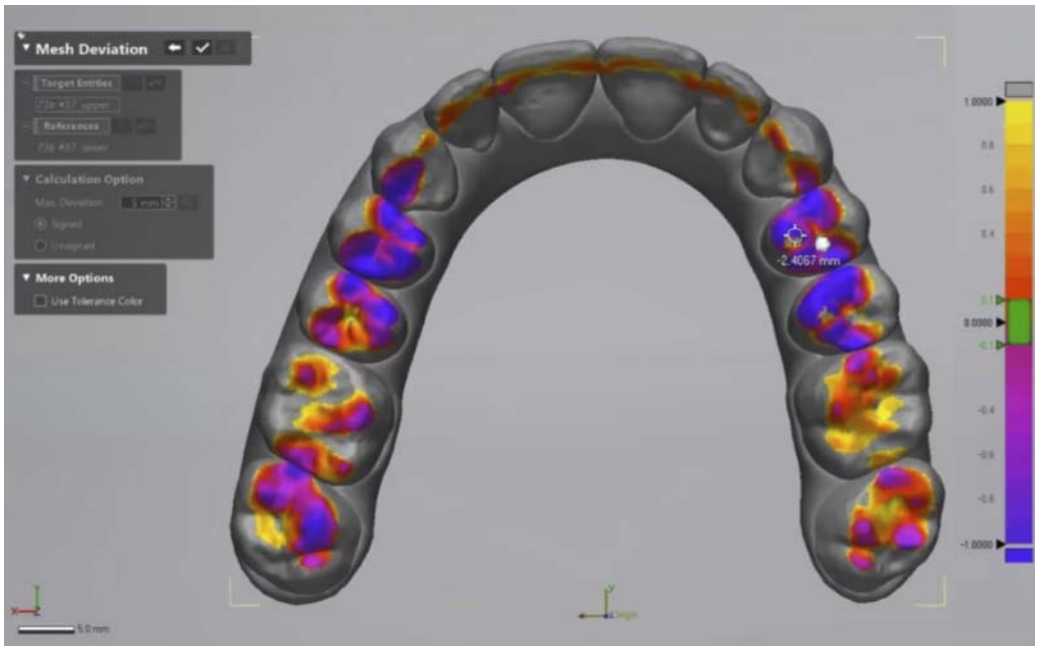

Figure 2. Overcorrection occlusal contact identification.

Table 1. Mean (SD) of Buccal and Palatal Occlusal Contacts of Maxillary Posterior Teeth at the Initial, Predicted, and Achieved Treatment Stages[a]

	Buccal			Palatal		
	Initial	Predicted [Change From Initial]	Achieved [Change From Initial]	Initial	Predicted [Change From Initial]	Achieved [Change From Initial]
Posterior	−0.26 (0.35)[b]	0.00 (0.22) [0.26 (0.34)]	−0.57 (0.33) [−0.31 (0.35)][c,e]	−0.03 (0.16)[b]	0.16 (0.16) [0.19 (0.32)]	−0.19 (0.10) [−0.16 (0.17)][c,e]
First premolar	−0.19 (0.35)[b]	−0.08 (0.27) [0.11 (0.41)][d,e]	−0.54 (0.43) [−0.35 (0.41)][e]	−0.06 (0.29)[b]	0.17 (0.34) [0.23 (0.48)][d,e]	−0.22 (0.39) [−0.16 (0.30)][d,e]
Second premolar	−0.27 (0.40)[b]	0.03 (0.29) [0.30 (0.46)][e]	−0.63 (0.49) [−0.36 (0.46)][e]	−0.05 (0.19)[b]	0.20 (0.38) [0.25 (0.55)][e]	−0.30 (0.36) [−0.25 (0.28)][e]
First molar	−0.25 (0.46)[d]	0.05 (0.26) [0.30 (0.45)][e]	−0.58 (0.40) [−0.33 (0.44)][c,e]	−0.05 (0.21)[d]	0.15 (0.21) [0.20 (0.31)][e]	−0.08 (0.21) [−0.03 (0.22)][c,e]
Second molar	−0.32 (0.53)[b]	−0.01 (0.28) [0.31 (0.53)][d,e]	−0.55 (0.47) [−0.23 (0.63)][c,e]	0.03 (0.13)[b]	0.11 (0.26) [0.08 (0.35)][d,e]	−0.14 (0.20) [−0.17 (0.24)][d,e]

[a] SD indicates standard deviation. Measurements are in millimeters. A positive change indicates an increase in contact. A negative change indicates a decrease in contact. A Bonferroni correction of 20 was applied.
[b] $P \leq .001$ demonstrates intervariable difference.
[c] $P \leq .01$ demonstrates intervariable difference.
[d] $P \leq .05$ demonstrates intervariable difference.
[e] $P \leq .001$ demonstrates intravariable difference.

teeth. An unpaired-sample *t*-test was applied to evaluate the difference between the absolute initial, predicted, and achieved means and the predicted and achieved change of the "normal" and overcorrection groups. A Bonferroni correction of 20 (the planned tests of occlusal contact) was applied for statistical significance of occlusal contact and set at $P \leq .0025$. Bonferroni corrections were conducted to lessen the possibility of a type I sampling error.[15] The number of statistical tests carried out was multiplied by the significance level of .05 to calculate the different statistical significance thresholds.

All measurements were repeated after a 2-week interval by the same operator to calculate intraoperator error using intraclass correlations. Statistical analysis was performed using Stata/IC software (version 15.1; StataCorp LLC., College Town, Tex).

RESULTS

The sample comprised 21 females and 12 males. The mean (SD) age of the patients was 32.7 years (SD, 13.12). Most (32/33) displayed pretreatment crowding, and one showed mild spacing. Table 1 indicates the mean (SD) buccal and palatal occlusal contacts of the maxillary posterior teeth at the initial, predicted, and achieved treatment stages. Table 2 shows the occlusal contact of all posterior teeth was significantly less than that predicted by the Invisalign software. Intraclass correlation scores for the assessed measurements were between 0.93 and 1, indicating excellent agreement.

The overcorrection group revealed a statistically significant difference in the predicted occlusal contact compared with the group with no overcorrection prescribed (the "normal" occlusal contact group) ($P \leq .0025$), but no statistically significant difference in achieved occlusal contact (Tables 3 and 4).

An exploratory analysis was conducted to extrapolate an estimate of OGS equivalent occlusal contacts. The loss of equivalent ABO-OGS occlusal contact points was 4.48 (SD, 4.01).

DISCUSSION

The findings of the present study indicated that there was a decrease in posterior occlusal contact in the clinically achieved outcome following treatment using the Invisalign appliance compared with the outcome predicted by the Invisalign digital treatment planning

Table 2. Mean (SD) of Maxillary Occlusal Contact at the Initial, Predicted, and Achieved Treatment Stages[a]

	Initial	Predicted [Change From Initial]	Achieved [Change From Initial]	Difference Between Predicted and Achieved	*P* Value
Overall	−0.12 (0.18)	0.03 (0.21) [0.15 (0.22)]	−0.34 (0.23) [−0.22 (0.22)]	−0.37	*
Anterior	−0.06 (0.19)	−0.11 (0.41) [−0.05 (0.38)]	0.25 (0.33) [−0.19 (0.38)]	0.36	NS
Posterior	−0.15 (0.21)	0.08 (0.20) [0.23 (0.27)]	−0.38 (0.25) [−0.19 (0.38)]	0.46	*
Individual teeth					
Central incisors	−0.13 (0.13)	−0.26 (0.61) [−0.13 (0.67)]	−0.32 (0.51) [−0.19 (0.70)]	−0.06	NS
Lateral incisors	−0.04 (0.14)	−0.26 (0.53) [−0.22 (0.51)]	−0.33 (0.42) [−0.29 (0.44)]	−0.07	NS
Canines	−0.01 (0.16)	0.19 (0.25) [0.20 (0.23)]	−0.11 (0.25) [−0.10 (0.22)]	−0.30	*
First premolars	−0.13 (0.22)	0.05 (0.23) [0.18 (0.32)]	−0.38 (0.33) [−0.25 (0.27)]	−0.43	*
Second premolars	−0.16 (0.25)	0.11 (0.30) [0.27 (0.40)]	−0.46 (0.30) [−0.30 (0.27)]	−0.57	*
First molars	−0.15 (0.27)	0.10 (0.21) [0.25 (0.31)]	−0.33 (0.28) [−0.18 (0.26)]	−0.43	*
Second molars	−0.14 (0.28)	0.05 (0.19) [0.19 (0.33)]	−0.35 (0.30) [−0.21 (0.37)]	−0.40	*

[a] SD indicates standard deviation; NS, nonstatistically significant. Measurements are in millimeters. A positive change indicates an increase in contact. A negative change indicates a decrease in contact. A Bonferroni correction of 20 was applied.
* $P \leq .001$.

Table 3. Mean (SD) of Overall Occlusal Contact According to Normal Contact and Overcorrection Contact Groups at the Initial, Predicted, and Achieved Treatment Stages[a]

	Initial	Predicted [Change From Initial]	Achieved [Change From Initial]	Difference Between Predicted and Achieved
Normal	−0.11 (0.19)	−0.04 (0.11) [0.07 (0.19)][b,c]	−0.33 (0.18) [−0.22 (0.23)][c]	−0.29
Overcorrection	−0.14 (0.16)	0.13 (0.28) [0.27 (0.23)][b,c]	−0.37 (0.29) [−0.23 (0.22)][c]	−0.50

[a] SD indicates standard deviation. Measurements are in millimeters. A positive change indicates an increase in contact. A negative change indicates a decrease in contact.
[b] $P \leq .05$ demonstrates intergroup difference.
[c] $P \leq .001$ demonstrates intragroup difference.

software processes. The popularity of Invisalign as a treatment modality and the potential impact of the findings and the effectiveness of the appliance on the management of malocclusion emphasize the relevance of this investigation.[1]

The mean age of the patients in the present study was 32.7 years. This corresponded with the mean age in similar studies and is typical of the age when CAT is commonly performed.[16–18] A mild-to-moderate Class I malocclusion in nongrowing patients was selected to minimize the potential confounding effects of growth and other malocclusion traits on the achievement of optimal occlusal contact. The sample size corresponded with the numbers assessed in previous studies assessing the same database.[3,11,19,20] The rigorous application of strict inclusion/exclusion criteria from a large database enabled the selection of an adequate sample size and the minimization of selection bias associated with retrospective studies.

Optimal occlusal contact enables maximum chewing efficiency, potentially minimizes the stresses delivered to the teeth during function, and may be crucial for a stable orthodontic outcome.[7,8,21] The achieved occlusal contact of all posterior teeth in the present study, however, was significantly less than that predicted by the Invisalign software. In addition, the achieved posterior occlusal contact was also less than the pretreatment initial posterior occlusal contact. For example, the second premolar experienced a decrease in occlusal contact from its initial position that equated to the value of the predicted increase in the Invisalign software. A proposed rationale for poor occlusal contact outcomes relates to the aligner material thickness in preventing occlusal contact.[22] A 2018 study suggested programming posterior tooth extrusion (overcorrection) of approximately 1.2 mm to counteract the "relative intrusive" effects of the material.[6] However, a subgroup analysis in the present study indicated that there was little difference in the actual occlusal contact of the overcorrection group compared with the normal contact group. A potential explanation is that the heavy contact produced by excess virtual overlap on the overcorrected ClinCheck digital model was not physically reproducible. An additional explanation relates to the inherent intrusive nature of aligner mechanics.[23] This may explain why the extrusion of teeth by the Invisalign appliance has achieved approximately 30% of the extrusion predicted by the aligner manufacturer's software in several studies.[24]

Earlier studies assessing occlusal contact following CAT reported poor occlusal contact when using the ABO-OGS assessment tool.[4,10,25] Buschang et al. compared a predicted occlusion with the actual end-of-treatment occlusion following Invisalign appliance treatment in 27 patients and found a statistically significant reduction of 1 OGS occlusal contact point from that predicted.[25] A recent meta-analysis concluded that CAT had a mean difference of 4.45 (95% confidence interval: 2.72, 6.18), that is, fewer occlusal contacts than FAT in the OGS assessment.[26] These findings agreed with the present data in which the estimated loss of OGS occlusal contacts was 4.48 (SD, 4.01). However, occlusal contact in the present study was measured

Table 4. Mean (SD) of Anterior and Posterior Occlusal Contact According to Normal Contact Treatment and Overcorrection Groups at the Initial, Predicted, and Achieved Treatment Stages[a]

	Anterior			Posterior		
	Initial	Predicted [Change From Initial]	Achieved [Change From Initial]	Initial	Predicted [Change From Initial]	Achieved [Change From Initial]
Normal	−0.07 (0.19)	−0.13 (0.34) [−0.06 (0.37)]	−0.27 (0.38) [−0.20 (0.42)]	−0.13 (0.24)	−0.01 (0.07) [0.12 (0.21)][b,c]	−0.35 (0.18) [−0.22 (0.21)][c]
Overcorrection	−0.04 (0.19)	−0.09 (0.51) [−0.05 (0.41)	−0.22 (0.25) [−0.18 (0.30)]	−0.17 (0.16)	0.21 (0.26) [0.38 (0.28)][b,d]	−0.43 (0.35) [−0.26 (0.25)][a]

[a] SD indicates standard deviation. Measurements are in millimeters. A positive change indicates an increase in contact. A negative change indicates a decrease in contact. A Bonferroni correction of 5 was applied.
[b] $P \leq .01$ demonstrates intergroup difference.
[c] $P \leq .01$ demonstrates intragroup difference.
[d] $P \leq .001$ demonstrates intragroup difference.

as a single buccal surface and single palatal or lingual surface value on the molars in contrast to the OGS that measures two cusps, resulting in a possible overestimation of the occlusal contact present.

The present study only assessed occlusal contacts at the end of the first aligner sequence and did not examine the effects of additional aligner sequences to refine the treated outcome. However, it is reasonable to consider that the same issues regarding the aligner material and treatment protocols in the management of occlusal contacts were present in the refinement phase. The findings from a recent survey would appear to support this.[1] Although posttreatment settling may increase the number of occlusal contacts, studies have indicated that these contacts were not ideal and did not reach the number of contacts recorded at baseline.[21,27,28] Optimizing occlusal contacts, therefore, should occur during active treatment.

The current study investigated occlusal contact by assessing interocclusal overlap, which is a virtual phenomenon that is not possible to apply on conventional models or the natural dentition. Although image stitching and occlusal registration accuracy may have affected results, the level of inaccuracy reported (Flügge et al. found iTero intraoral full-arch scanning accurate to 50 μm[29]) was not large enough to explain the overlap observed in the present study.[30] The scanner angle during bite registration, periodontal ligament compressibility when patients are occluding, and bite force at the time of registration were all potential factors to explain this observed overlap.[31–33]

The limitations of this research included its retrospective nature, which risked bias in the selection of the patients. In addition, the present study was limited to a static occlusal analysis and was unable to identify occlusal contacts that occurred in excursive functional movements. In addition, the findings of the present investigation, therefore, are only valid for similar mild-to-moderate Class I patients.

Further investigation is required to determine occlusal contact changes associated with the Invisalign appliance following the refinement phase and for more complex malocclusions. Research is also required to account for the deficiencies between the predicted outcome and the achieved clinical outcome and, further, to determine the changes in treatment protocols that may address the deficiencies. In addition, future relevant studies will also need to incorporate ongoing changes in CAT protocols, aligner material, and treatment planning software.

CONCLUSIONS

- Treatment using the Invisalign appliance results in decreased posterior occlusal contact compared with the outcome predicted by appliance software.
- Overcorrection of posterior occlusal contact during digital treatment planning does not make a difference in the achieved posterior occlusal contact.
- Further research is required to account for the deficiencies between the predicted outcome and the achieved clinical outcome and determine the corrective changes required in the treatment protocols.

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