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How well does Invisalign ClinCheck predict actual results: A prospective study

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Abstract

Introduction: This study aimed to compare achieved movements with predicted movements after 28-week use of Invisalign Lite aligners.

Settings and Sample Population: The digital impressions of 21 subjects treated with Invisalign Lite at a private practice and in the dental clinic (Milan, Italy) were taken and analysed. Subjects were Caucasian with a mean age of 20.1 years.

Methods: Patients were analysed at two time points: at T0, before starting therapy, and at T1, after 28 weeks of treatment with Invisalign clear aligners, with a 2-week change interval. The changes that occurred between T0 and T1 were compared to the predicted changes between T0 and Ts (setup/ClinCheck). Tooth movement performance was estimated through variables calculated as the difference between obtained and planned movements.

Results: In both maxillary and mandibular arches, the teeth that exhibited the least accurate expression of torque were the central incisors. Tip was not accurate on maxillary central incisors and canines, mandibular central incisors, lateral incisors, first premolars, second premolars and first molars. Rotations were under-expressed on maxillary lateral incisors, canines and second premolars and on mandibular central incisors, canines, first premolars, second premolars and first molars. The overall angular changes showed a tendency to underperformance. Transverse linear changes were accurate with a significant overperformance on maxillary and mandibular first molars.

Conclusions: Torque correction of maxillary central incisors, as well as rotational correction of most of the teeth, showed significant differences between what was planned and what was obtained.

KEYWORDS
clear aligners, ClinCheck, Invisalign Lite, tooth movements

1 | INTRODUCTION

Since the introduction of Invisalign on the market of clear aligners, orthodontists have questioned the ability of a virtual setup to predict real tooth movements. Studies evaluating how the planned treatment is related to the actual result are useful for clinicians who remain sceptical regarding clear aligner therapy. Some recent systematic reviews have analysed the efficacy of clear aligners in controlling orthodontic tooth movement.[1–5] Since then, other studies have reported the predictability of some very limited tooth movements (e.g. transverse changes measured on 3D models,[6,7] overbite correction,[8] lower incisor intrusion measured on lateral cephalometric radiographs,[9,10] rotation of the canines,[10] root control,[2] space closure after first premolar extraction[11] and incisor torque[12]). By measuring only one aspect of the therapy in each study, it is difficult to understand what is really predictable in clear aligner therapy (CAT). To date, few studies have reported the results of different tooth movements on anterior teeth.[13–16] Kravitz et al[13] focused on patients presenting anterior crowding, without specifying a measurement methodology. They concluded that, in general, movements had a relatively poor accuracy, of 41% overall, when comparing achieved movements to those predicted with ClinCheck. Simon et al[14] conducted an experimental study focusing on incisor torque, premolar derotation and molar distalization by applying these movements on different patients, but these studies were performed before several of the recent improvements to Invisalign had been introduced. A recent study by Grünheid et al[15] described accurately specific differences in linear and angular measures on a sample of 30 cases treated with Invisalign; however, the duration of treatment was not reported.

As CAT is under constant development and is claimed to reach the same performance as fixed orthodontic treatment, supporting scientific evidence is still lacking.

The purpose of this study was to provide a comprehensive assessment of the accuracy of tooth movement and dental arch changes (linear and angular) in 21 consecutively treated patients using dual-arch Invisalign Lite therapy by comparing achieved movements with those that were predicted. As a secondary outcome, the effectiveness of different auxiliaries, such as attachments and interproximal reduction (IPR), was evaluated. The null hypothesis was that there would be no significant difference between the movements that were predicted in ClinCheck and the actual tooth movements measured (performance).

2 | MATERIALS AND METHODS

2.1 | Sample

The study was approved by the Medical Ethics Committee of the University Vita-Salute San Raffaele Hospital, Milan, Italy (reference no. 106/NT), and the parents or guardians of each participant signed informed consent forms. All methods used in the study were non-invasive, and the authors did not receive financial support for this research.

This was a prospective cohort study including 21 consecutive subjects treated with Invisalign Lite from September 2022 to June 2023. All patients were treated at a private practice and in the dental clinic (Milan, Italy), by the same operator (LHG), experienced in CAT. Subjects were Caucasian: 12 females and 9 males with a mean age of 20.1 years (range: 18-26 years) at the time of treatment start. The inclusion criteria were as follows: (1) no previous orthodontic treatment or teeth extraction; (2) permanent dentition stage (excluding third molars not received) with, at least, a visible half crown of second molars; (3) Class I or slightly Class I and in which the molar classification was not changed during the CAT (no elastics were used); (4) presence of an initial discrepancy index value smaller or equal to 15 points, which means low case complexity[17,18]; and (5) respecting the inclusion criteria for Lite therapy provided by Align Technology: less than 6 mm of anterior crowding, maximum of 3 mm of expansion needed, maximum of 3 mm of open bite/overbite correction and maximum of 15° of rotation correction needed per tooth. Exclusion criteria were as follows: (1) non-compliant patients; (2) presence of multiple and/or advanced caries; (3) tooth agenesis; (4) supernumerary teeth; (5) bad oral habits; (6) craniofacial syndromes or general diseases; (7) cleft lip/palate; (8) periodontal disease; (9) prosthetic rehabilitation; and (10) patients who need orthognathic surgery and those with incongruous diagnostic records.

2.2 | Clinical protocol

The treatment protocol was highly standardized, following that predetermined for Invisalign Lite cases. ClinCheck 3D features were used to manually adjust the setup until the treating clinician was satisfied. All optimized attachments were left as suggested by ClinCheck. No treatment auxiliaries, such as elastics or chains, were used. Interproximal reduction was performed, if needed, only on anterior teeth. The number of aligners provided to the patients was always 14, as that is the maximum number of aligners provided as Lite therapy. The patients were invited to self-report any minor or major problems relative to compliance, but none were reported.

2.3 | Measurements and timing

Patients were instructed to wear the aligners 20-22 hours per day. The clinician did not have any suspicion of poor compliance during clinical examinations. All patients were instructed to change the aligners on a 2-week basis.

At the first appointment, the aligners were delivered with no attachments to allow a comfortable start of aligner therapy. Similarly, no IPR was performed at stage 1. Four weeks later, before the third aligner, attachments were placed and IPR was performed. In general, patients were seen for a clinical check between the 12th and 16th weeks of aligner use. They were then seen between the 24th and 28th weeks of use to collect new impressions that would serve as a new starting point for refinement therapy (19 out of 21 patients) or as references for constructing a fixed bonded retainer (2 out of 21).

If overcorrection was planned, patients were seen at the 24th week/aligner, after the use of the first overcorrection set of aligners (6 out of 21). If no overcorrection (virtual power chain) was planned, patients were seen at the end of the 14th aligner (15 out of 21).

Patients' initial and final records included digital impressions that were taken with an intraoral scanner (Trios3, 3shape, Denmark). The initial malocclusion (T0) and the approved ClinCheck setup (Ts) were retrieved from the first approved ClinCheck. The new initial malocclusion of the refinement ClinCheck (second-approved ClinCheck) served as the final model (T1) of the first period of correction, to be compared with the predicted outcome (Ts).

Measurements were performed at the Department of Orthodontics, School of Dentistry, Vita-Salute San Raffaele University, Milan, Italy, on 3D models downloaded as .stl files from the Invisalign ClinCheck software, using VAM software (Vectra, Canfield Scientific, Fairfield, NJ, USA).

A single operator (AL) performed all measurements on blind files and collected them into a dedicated spreadsheet.

Measurements were performed, without the need for further radiographic investigations, according to the protocol already published and implemented in other studies.[12,19,20]

A total of 62 anatomical reference points were digitized on each model from right to left first molars by the first operator (AL). The protocol was described by Huanca Ghislanzoni et al[19,20] using VAM software (Vectra, Canfield Scientific). Sequencing and positioning of all the points were double-checked by a second expert operator (LHG).

Incisors, canines and premolars were represented by 5 landmarks, determining the mesio-distal axes, the facial axis of clinical crown (FACC) and a gingival point on the lingual side corresponding to the projection of the FACC axis on the lingual side, while the first molars were represented by 6 landmarks, as the mesio-buccal cusp mark was additionally included in order to determine the occlusal plane, as described by Andrews[21] Thereafter, models at T0 and T1 were superimposed, with a best-fit operation on the digitized marks, and the coordinates were converted as a set of x, y, z numbers, using the occlusal plane of the model at Ts, which represented the ideal correction as a reference (Figure 1).

For each tooth, angular measurements of torque, tip and rotation were calculated.

Torque was measured as the labiolingual inclination of the FACC with regard to the reference plane as described by Andrews[21] The sign of the angular value was positive for measures that are associated with vestibular crown inclination and negative when there was a lingual crown inclination.

Tip was calculated as the mesial or distal inclination of the FACC with regard to a line perpendicular to the occlusal plane (positive values were associated with mesial inclination and negative values with distal inclination).

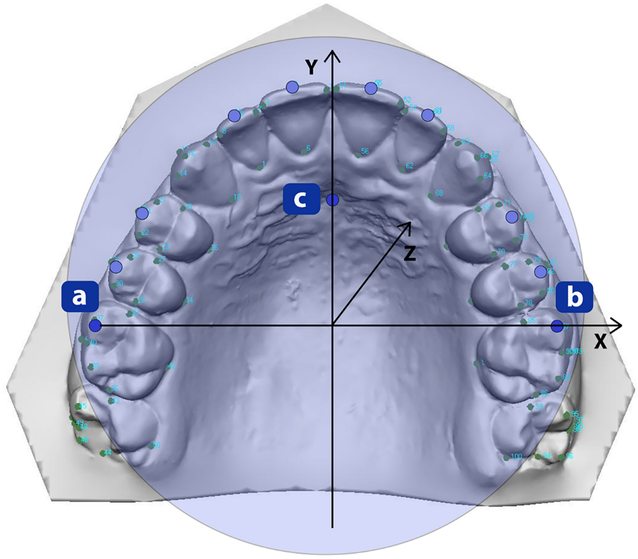

FIGURE 1 The three-dimensional coordinate system with the *X*-, *Y*- and *Z*-axes. The *X*-axis represents the transversality, the *Y*-axis the sagittality and the *Z*-axis the verticality.

Rotation was calculated as the angle between the mesio-distal axis of each tooth with respect to the x-axis connecting the mesio-buccal cusp of the first molars.

Linear measurements related to the entire dental arch were also calculated. They included transverse distances at the level of canines, premolars and first molars. Transverse intercuspidal (buccal) distances were calculated as the linear distance from the cusps of canines, the buccal cusps of first and second premolars and the mesio-buccal cusps of first molars.

Thereafter, differences between T1 and T0 (T1-T0, obtained movement) and Ts and T0 (Ts-T0, planned movement) were calculated.

Tooth movement performance (performance) was estimated through variables calculated as the difference between obtained and planned movements, expressing underperformance as negative and overperformance as positive. Mean, minimum (min) and maximum (max) values were calculated for performance on torque, tip and rotation.

2.4 | Statistical analysis

The sample size calculation was calculated using the G*Power software, based on previously conducted studies.[19] Data distribution of variables was explored through the Shapiro-Wilk test. The hypothesis that the data were normally distributed could not be rejected for any variable.

The Dahlberg formula was used to calculate intra-operator error by measuring 10 different models on VAM software at two different time points (14-day time interval).[22] Linear discrepancies >0.5 mm and angular discrepancies above 1.5° were considered of clinical significance, according to the American Board of Orthodontics criteria.[23] No significant systematic errors were found between the measurement sessions.

Outcome values for teeth on the right side were compared to those for teeth on the left side, and skewness was estimated to check for asymmetry of distribution. Being normally distributed, data on both right and left sites were analysed together, without accounting for differences between the sides. Therefore, each group of tooth measurements included 30 teeth (21 patients).

The hypothesis is that the data we normally distributed could not be rejected for any variable.

Descriptive statistics were evaluated for all linear and angular measurements at T0 (pre-treatment), T1 (at the end of the 14 stages) and Ts (ClinCheck as approved).

Differences between expected outcomes (Ts-T0) and movements that actually occurred (T1-T0) were estimated using a paired *t*-test.

The influence of different variables such as attachments, IPR and jaw on tooth movements was analysed through multilevel mixed-effects linear regression models to take into account within-subject correlations. For fitting regression models, the dependent variable (performance) was considered as its absolute value, expressing only the discrepancy between the achieved and planned movement.

All tests were two-tailed, and all statistical comparisons were conducted at the .05 level of significance. Statistical analysis was conducted using StatPlus software (StatPlus Pro; AnalystSoft Inc., version v6, Walnut, CA, USA) and Stata version 13 (Stata Statistical Software, release 13.0; StataCorp, Lakeway Drive, College Station, Texas, USA).

3 | RESULTS

The results of intra-operator repeatability error indicated 0.2 mm of error for linear measures and 0.7 degree for angular measures, which were less than the pre-established values of clinical relevance.[20]

Table 1 reports values of crown torque for all teeth at T0, T1 and Ts and respective differences between planned (T0-Ts) and obtained (T0-T1) results. The last column represents the movement performance, where mean underperformance was observed for almost all teeth, as well as cases of overperformance, considering that all max values were positive. This means that, in some cases, movements resulted in overcorrection. In the maxillary arch, the two teeth that exhibited the least accurate expression of torque were the central incisor ($P=.001$) and the first molar ($P=.01$). Similarly, in the mandible, the first molar ($P=.001$) and the central incisor ($P=.01$) showed the most significant difference between planned and obtained movements.

Mesio-distal angulation (tip) values are shown in Table 2. Again, the least precise movement in the maxillary arch was the tip of central incisors ($P=.001$). Tip of the mandibular incisors was less accurate than expected, with the lateral incisors exhibiting the least precise tip expression ($P=.001$). Second premolars ($P=.001$) and first molars ($P=.001$) also resulted in less accurate tip than expected. Tip for all teeth resulted in slight mean underperformance.

In terms of rotations in the maxillary arch, the lateral incisor showed the least accurate movement ($P=.001$) (Figure 2) followed by the canine ($P=.01$) and the second premolar ($P=.01$) (Table 3). In the mandibular arch, rotation of premolars and molars was less

TABLE 1 Values of crown torque for all teeth at T0, T1 and Ts and respective differences between planned (T0-Ts) and obtained (T0-T1) results.

	T0 mean (SD)	T1 mean (SD)	Ts mean (SD)	T1-T0 mean (SD)	Ts-T0 mean (SD)	*P*-value	Performance[a] mean (min, max)
Maxillary arch							
Central incisors	13.3 (6.0)	12.9 (4.4)	14.5 (3.1)	−0.3 (3.1)	1.2 (4.8)	.00**	−1.9 (−8.6, 3.1)
Lateral incisors	10.8 (6.4)	9.0 (4.7)	8.9 (3.9)	−1.9 (3.4)	−2.0 (5.3)	.99	−2.0 (−7.1, 2.8)
Canines	−3.3 (9.2)	−1.8 (7.1)	−1.6 (6.1)	1.5 (5.0)	1.7 (6.0)	.52	−1.4 (−6.9, 1.8)
First premolars	−10.0 (6.8)	−6.8 (5.3)	−5.9 (4.1)	3.2 (3.7)	4.1 (4.2)	.01*	−1.5 (−6.7, 4.1)
Second premolars	−10.4 (7.0)	−8.1 (5.4)	−7.7 (5.1)	2.3 (3.7)	2.8 (4.8)	.21	−1.2 (−7.4, 2.3)
First molars	−12.7 (9.2)	−14.0 (5.6)	−14.8 (5.4)	−1.3 (7.7)	−2.0 (8.0)	.00**	−0.4 (−4.9, 4.1)
Mandibular arch							
Central incisors	15.9 (7.4)	14.7 (5.3)	15.7 (5.0)	−1.1 (4.6)	−0.1 (5.6)	.00**	−0.9 (−5.3, 2.6)
Lateral incisors	11.1 (5.4)	11.4 (5.2)	12.2 (5.3)	0.3 (3.0)	1.1 (4.1)	.02*	−1.3 (−4.8, 2.8)
Canines	−5.0 (7.8)	−2.4 (6.1)	−2.5 (5.3)	2.7 (4.0)	2.6 (5.0)	.25	−0.4 (−16.3, 4.6)
First premolars	−12.3 (6.0)	−10.5 (5.9)	−11.4 (5.9)	1.8 (3.5)	0.9 (4.5)	.01*	−1.2 (−8.7, 7.7)
Second premolars	−21.5 (9.0)	−19.8 (7.7)	−20.8 (6.9)	1.7 (3.8)	0.7 (5.2)	.01*	−1.1 (−5.8, 4.1)
First molars	−31.1 (7.3)	−29.9 (6.7)	−31.7 (6.7)	1.2 (3.3)	−0.6 (3.8)	.00**	−0.8 (−7.0, 5.1)

Abbreviations: T0, pre-treatment; T1, obtained post-treatment; Ts, planned post-treatment.

[a]Performance: negative values indicate underperformance (undercorrection); 0 values indicate achieved result (correction); and positive values indicate overperformance (overcorrection).

*$P<.05$; **$P<.01$.

TABLE 2 Values of mesio-distal angulation (tipping) for all teeth at T0, T1 and Ts and respective differences between planned (T0-Ts) and obtained (T0-T1) results.

	T0 mean (SD)	T1 mean (SD)	Ts mean (SD)	T1-T0 mean (SD)	Ts-T0 mean (SD)	*P*-value	Performance mean (min, max)
Maxillary arch							
Central incisors	4.8 (6.0)	4.5 (3.1)	5.7 (2.3)	−0.2 (3.5)	0.1 (5.0)	.00**	−1.9 (−6.8, 0.6)
Lateral incisors	14.7 (5.3)	12.9 (3.6)	13.0 (2.6)	−1.9 (3.4)	−1.7 (4.7)	.46	−1.4 (−6.0, 2.1)
Canines	19.5 (6.3)	17.9 (4.7)	16.8 (3.6)	−1.6 (3.1)	−2.6 (4.7)	.02*	−1.9 (−7.0, 1.5)
First premolars	15.7 (4.4)	16.4 (3.0)	17.1 (2.4)	0.8 (2.9)	1.4 (4.2)	.09	−1.6 (−5.9, 2.4)
Second premolars	15.2 (4.8)	19.5 (4.4)	15.3 (4.0)	−0.2 (2.2)	0.2 (3.3)	.16	−1.1 (−5.3, 3.2)
First molars	13.8 (7.7)	15.6 (5.2)	15.4 (4.3)	1.8 (4.4)	1.6 (5.2)	.64	−1.1 (−7.5, 5.1)
Mandibular arch							
Central incisors	−1.2 (6.2)	0.2 (4.0)	1.7 (2.2)	1.4 (3.1)	2.9 (5.2)	.00**	−2.0 (−13.9, 2.9)
Lateral incisors	7.1 (5.0)	4.8 (3.2)	7.0 (2.5)	−2.3 (4.1)	−0.1 (5.0)	.00**	−1.3 (−8.4, 5.7)
Canines	18.6 (7.2)	15.9 (5.6)	15.9 (3.0)	−2.7 (4.1)	−2.7 (6.4)	.62	−2.1 (−12.4, 5.3)
First premolars	19.6 (6.3)	20.0 (4.4)	18.6 (2.8)	0.4 (3.2)	−1.0 (5.4)	.00**	−2.2 (−11.5, 3.5)
Second premolars	23.8 (5.2)	21.9 (3.3)	19.8 (2.8)	−2.0 (3.9)	−4.0 (4.6)	.00**	−1.8 (−11.8, 2.5)
First molars	21.6 (5.2)	20.8 (4.2)	19.4 (3.5)	−0.8 (3.1)	−2.2 (4.3)	.00*	−2.0 (−9.1, 5.9)

Abbreviations: Perf, performance; T0, pre-treatment; T1, obtained post-treatment; Ts, planned post-treatment.
*$P<.05$; **$P<.01$.

precise than the rest of the teeth, with the second premolar being the most difficult ($P=.001$) (Figure 2). The tooth that underperformed most on average was the maxillary lateral incisor (−4.2°), showing a low tendency to obtain the predicted result or overcorrecting (min −21.2, max 3.0).

The overall angular changes showed a tendency to underperform: −1.0° on average for torque changes, −1.6° for tip and −2.4° for rotations.

Changes in transverse dimensions were quite accurate in the maxillary arch, with the intermolar width being slightly greater than expected ($P=.01$) (Table 4). In the mandible, the mean intermolar distance obtained was, on average, smaller than planned ($P=.001$).

Overall, optimized attachments were placed on 227 teeth: 120 in the maxilla and 107 in the mandible. They were primarily positioned on canines and premolars and only a few (32) on upper incisors. No attachments were placed on molars. Fitted mixed models controlling for intra-patient interaction, adjusted for jaw, IPR and type of tooth, did not indicate a significant influence of attachment presence on torque (coef. .03, $P=.87$) and tip (coef. .09, $P=.72$), whereas it seemed to influence rotation (coef. .9, $P=.012$). This means that the presence of attachments increases, as a mean, the performance of rotation by 1.4°.

The presence of IPR on incisors and canines seemed to have an effect on torque expression (coef. .6, $P=.03$) and no effect on tip (coef. .4, $P=.37$) and rotation (coef. .9, $P=.11$). According to the model controlling all the variables, no difference was noticed between the upper and lower jaws in expressing torque and tip, whereas the upper jaw seemed to perform better than the lower jaw in terms of rotation expression (coef. 1.39, $P=.002$).

4 | DISCUSSION

Patient selection was severe: only those patients eligible for Invisalign Lite treatment were included as consecutively treated cases, thus reducing the influence of potential sources of variability and bias associated with complex orthodontic cases. All patients in the study self-reported good compliance with the prescribed treatment protocol, and the main operator was able to confirm adherence to the instructions given (compliance was high also because it concerned the first 28 weeks of the treatment, while it may have dropped for a longer period of time). Other sources of systematic error related to measurement methods were limited by implementing a measurement system that has been shown to be reliable and that did not rely solely on anatomically stable structures.[19]

It is difficult to compare the current data with those reported by other studies as the methodology used was not comparable.[13,14,20,24–26] Our work aimed to analyse dental movements and changes of the dental arch with the Invisalign Lite system, and so far, only the recent study conducted by Zhou and Guo[27] has evaluated these aspects; however, their analysis requested CBCT to be performed at the beginning and at the end of the orthodontic treatment. This procedure required further radiological investigations on the patients though, in our assessment, this was not necessary due to the investigation protocol adopted.

Recent articles by Tie et al[28] and Goh et al[29] have analysed the prediction effectiveness of ClinCheck software; however, their analyses mainly evaluated comprehensive cases. They, therefore, have a greater duration and a greater number of refinements available and do not highlight how many of these were requested or state the

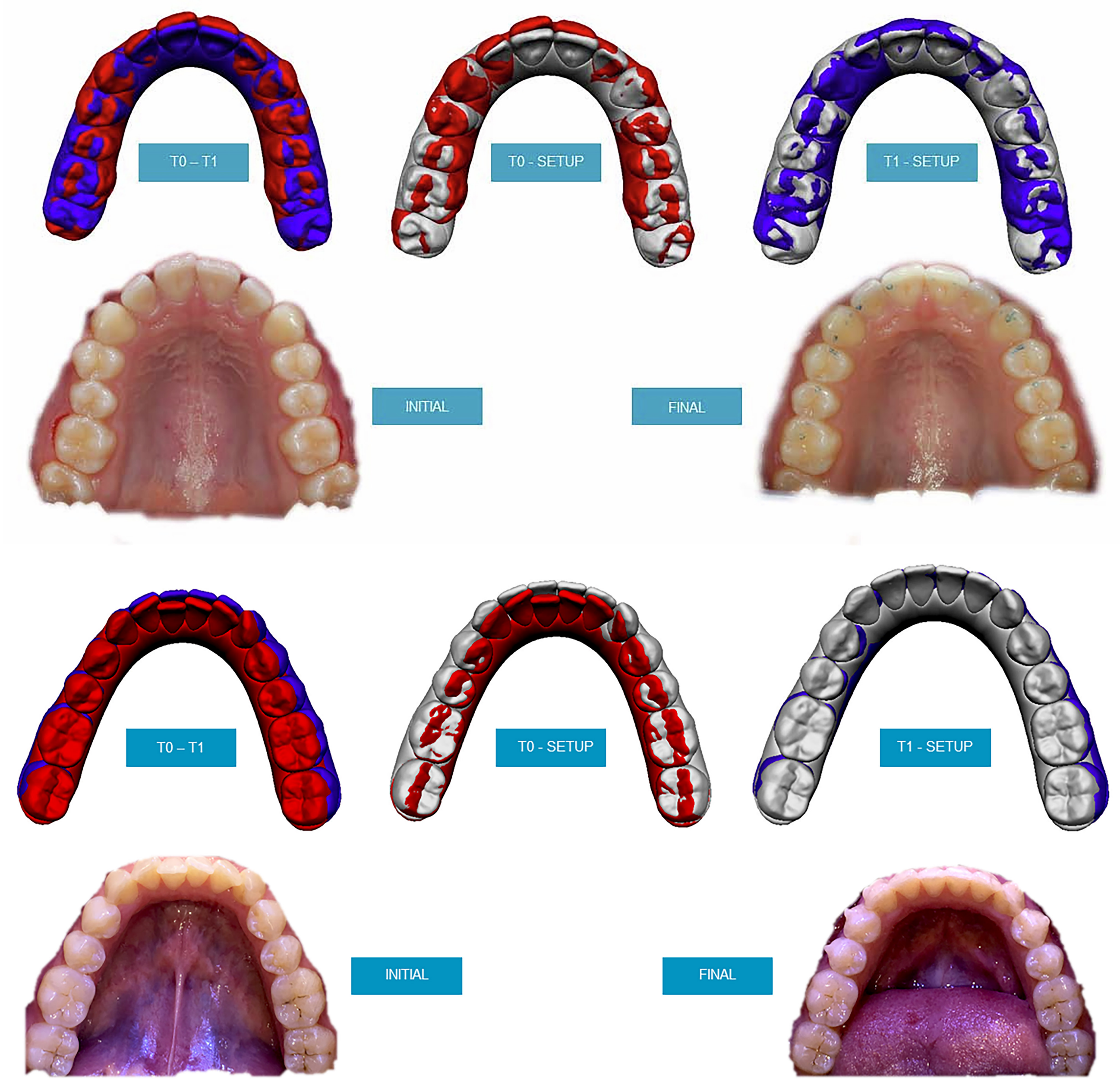

FIGURE 2 Superimposition of pre- and post-treatment models. There is a difference in the rotation of teeth 1.2, 2.2, 3.4 and 4.4 between initial (T0, red), obtained movement (T1, blue) and virtual planned movement (Ts, grey).

overall duration of the therapy. Furthermore, they mainly focused on the expansion obtainable in a group of adult patients[28–30] and on the modifications of the Wilson curve of the mandibular arch,[29] without analysing the predictability of single tooth movements obtainable with the aligners.

Actually, while we tried to calculate a percentage of success/achievement of actual movement vs planned movement, the great variability among patients made it impractical to report such an indicator as a percentage. In fact, when small movements were planned, the actual movement was sometimes much greater proportionately which might be confusing and difficult to interpret clinically (e.g. a planned movement of −0.5° resulting in a real movement of −2.0° would be a −400% clinical performance compared with a real movement of −0.5° for a planned movement of −2.0°, which yields a clinical performance of 25%). An indicator of performance was used instead of a percentage. This simply described how much more or less than what was planned was effectively achieved.

All angular movements (torque, tip and rotation) showed an average underperformance that ranged from −2.2° to 0.0° for torque, from −2.5° to −0.9° for tip and from −4.5° to −0.9° for rotations.

Tip correction was particularly under-expressed for mandibular second premolars (−1.8°) and first molars (−2.0°). In particular, when

TABLE 3 Values of rotation for all teeth at T0, T1 and Ts and respective differences between planned (T0-Ts) and obtained (T0-T1) results.

	T0 mean (SD)	T1 mean (SD)	Ts mean (SD)	T1-T0 mean (SD)	Ts-T0 mean (SD)	P-value	Performance mean (min, max)
Maxillary arch							
Central incisors	11.0 (8.0)	10.3 (4.6)	10.2 (2.2)	−0.7 (4.3)	−0.8 (7.3)	.44	−2.3 (−10.0, 1.3)
Lateral incisors	34.9 (9.5)	34.3 (6.6)	30.9 (3.4)	−0.6 (4.7)	−4.0 (7.9)	.00**	−4.2 (−21.2, 3.0)
Canines	59.8 (11.5)	58.1 (6.5)	55.4 (5.1)	−1.7 (10.6)	−4.5 (12.1)	.01*	−4.0 (−12.2, 9.7)
First premolars	74.6 (7.9)	71.7 (4.9)	71.4 (3.9)	−3.0 (5.6)	−3.3 (6.8)	.60	−1.2 (−7.9, 4.5)
Second premolars	71.4 (9.2)	70.3 (6.8)	71.5 (6.1)	−1.1 (4.6)	0.1 (6.2)	.01*	−2.0 (−8.3, 4.5)
First molars	76.4 (6.0)	77.7 (4.9)	78.3 (5.1)	1.4 (3.6)	2.0 (3.8)	.13	−0.9 (−5.3, 4.0)
Mandibular arch							
Central incisors	2.4 (7.0)	4.5 (5.1)	5.3 (4.4)	2.1 (3.7)	2.9 (4.9)	.02*	−1.3 (−7.0, 4.0)
Lateral incisors	25.0 (6.2)	24.3 (3.8)	23.8 (3.1)	−0.8 (4.0)	−1.2 (5.9)	.52	−1.7 (−8.3, 2.2)
Canines	55.0 (12.0)	50.8 (8.5)	49.2 (5.8)	−4.2 (6.0)	−5.7 (8.3)	.03*	−2.6 (−17.0, 5.2)
First premolars	63.3 (11.6)	61.7 (8.2)	64.4 (4.8)	−1.7 (6.5)	1.1 (9.6)	.00**	−3.0 (−23.1, 7.2)
Second premolars	68.6 (10.8)	69.0 (7.0)	71.5 (5.9)	0.5 (6.0)	2.9 (8.0)	.00**	−2.6 (−14.8, 2.7)
First molars	73.0 (6.0)	74.0 (5.0)	75.1 (4.7)	0.9 (2.9)	2.0 (3.9)	.01*	−1.8 (−9.9, 1.9)

Abbreviations: Perf, performance; T0, pre-treatment; T1, obtained post-treatment; Ts, planned post-treatment.
*$P<.05$; **$P<.01$.

TABLE 4 Values of transverse dimensions on the maxillary arch and mandibular arch at T0, T1 and Ts and respective differences between planned (T0-Ts) and obtained (T0-T1) results.

	T0	T1	Ts	T1-T0	Ts-T0	P-value
Maxillary arch						
Canine–canine	33.6 (2.4)	34.0 (2.2)	34.2 (2.0)	0.4 (1.1)	0.6 (1.1)	.10
First premolar–first premolar	41.3 (3.0)	42.2 (2.6)	42.2 (2.4)	0.9 (1.2)	0.9 (1.1)	.81
Second premolar–second premolar	46.7 (3.1)	47.9 (2.8)	47.6 (2.6)	1.2 (1.2)	1.0 (1.2)	.16
First molar–first molar	51.4 (2.6)	52.1 (2.7)	51.5 (2.3)	0.7 (0.7)	0.1 (0.7)	.01*
Mandibular arch						
Canine–canine	25.6 (1.8)	26.2 (1.7)	26.0 (1.5)	0.6 (1.0)	0.4 (1.1)	.02*
First premolar–first premolar	34.1 (2.7)	34.6 (2.2)	34.4 (2.1)	0.5 (1.2)	0.3 (1.2)	.16
Second premolar–second premolar	39.5 (3.0)	40.4 (2.5)	40.0 (2.3)	1.0 (1.4)	0.6 (1.7)	.10
First molar–first molar	45.5 (2.0)	46.3 (1.9)	45.7 (1.8)	0.8 (0.7)	0.2 (0.5)	.00**

Abbreviations: T0, pre-treatment; T1, obtained post-treatment; Ts, planned post-treatment.
*$P<.05$; **$P<.01$.

uprighting was planned for both first molars and second premolars, it was practically unexpressed for first molars and barely expressed for second premolars.

Rotational correction of maxillary lateral incisors (−4.2°) and canines (−4.0°) was particularly under-expressed. This was a common finding as additional rotation for lateral incisors and canines was the main problem that was left once planning the refinement. Additionally, rotations of the maxillary second premolars (−2.0°) and mandibular first (−3.0°) and second premolars (−2.6°) were consistently under-corrected. While analysing the effects from auxiliary clinical procedures, it was evident that the presence of attachments improved the performance of rotation by an average of 1.4°, making it more predictable to achieve rotational goals when attachments were present.

In agreement with Simon et al,[14] the present data indicated some loss of positive crown torque expression for incisors, particularly for central incisors. Even if the data suggested a clinically non-relevant loss of programmed torque, caution must be paid when higher levels of positive torque are required, especially during space closure or incisor retraction. In terms of tip expression, mandibular lateral incisors seem to be the teeth most lacking in movement expression and this also corresponds to a common clinical situation found at the end of cases with mandibular incisor crowding, which is a major cause of the need for additional aligners. On the other hand, maxillary lateral incisors presented the highest imprecision during rotation, with an average discrepancy of 4.2°.

In the present study, we observed that a statistically significant amount of expansion occurred at both the upper and lower first molars when almost no expansion was planned. Although 0.7 mm of non-planned expansion is not clinically significant, these findings suggest a role of anchorage for the first molars when trying to solve anterior crowding, even though no expansion may be planned. For research, when using superimposition on molars to estimate movements of other teeth, it may be misleading if the molars, as the reference, actually moved. Incidentally, accuracy of transverse movements was found to be high.

There are multiple factors that may explain the imprecision of the system, and it is difficult to identify the relative contribution of each factor. The clinician's experience should not be of major influence since Lite cases were not particularly complex. Another aspect to consider is the precision of the process through which the ClinCheck setup translates into the sequence of aligners. As a computerized process, it is subject to a margin of error that, unfortunately, we cannot calculate or take into account during our setup programming. Acknowledging and quantifying the imprecision of the system would help to programme cases more efficiently, planning overcorrection or appropriate additional auxiliaries if necessary (e.g. the presence of attachments improves the expression of rotational movements).

5 | CONCLUSIONS

When using the Invisalign Lite appliance for the treatment of low case complexity:

- The actual clinical changes after completing a prescription of Invisalign Lite clear aligners over 28 weeks tend to be selectively different from the virtual correction predicted.
- While transverse linear changes seem to be highly predictable, angular changes are generally under-expressed. The teeth that are most affected by underperformance are as follows: maxillary and mandibular central incisors and first molars for torque; mandibular second premolars and first molars for tip; and maxillary lateral incisors and canines, maxillary and mandibular second premolars and mandibular first premolars for rotations.

AUTHOR CONTRIBUTIONS

L.H.G. contributed to conceptualization, methodology, formal analysis and software. Z.K. contributed to conceptualization, formal analysis, methodology and software. M.M. contributed to data curation and writing – original draft preparation. C.M. contributed to supervision and editing. A.P. contributed to conceptualization and editing. A.L. contributed to conceptualization, methodology, and writing – original draft preparation and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author (AL) upon reasonable request.

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