Efficacy of planned moderate to severe torque changes in mandibular central incisors with an initial series of Invisalign aligners: a retrospective cohort study

Nancy Rajan[a]; Tony Weir[b]; Maurice J. Meade[c]

ABSTRACT

Objectives: To determine whether the achieved mandibular central incisor lingual root torque (LRT) changes matched the planned changes after treatment with an initial series of Invisalign aligners when ≥10° of torque change was planned.

Materials and Methods: A sample of adult patients who underwent treatment with the Invisalign appliance between 2013 and 2021 were evaluated. The pretreatment, planned, and achieved posttreatment digital models were measured using Geomagic Control X metrology software. The effect of age, number of prescribed aligners, sex, the presence of power ridges (PRs), and differing weekly wear protocols (WPs) in relation to the achieved LRT changes were determined.

Results: Seventy mandibular central incisors from 35 patients satisfied inclusion criteria. The accuracy of the achieved lower incisor LRT compared with that planned was 58.2%. Underexpression of planned torque changes was observed in most incisors (N = 66; 94.3%), with a clinically significant shortfall (≥5°) observed in 68.6% (N = 42) teeth. Patient age, sex, the WP, or the presence of PRs did not influence the differences between planned and achieved outcomes ($P > .05$). The prescribed number of aligners was influential in the difference between the planned and achieved torque outcomes ($P < .01$).

Conclusions: Underexpression of mandibular central incisor root torque was observed in most incisors in patients when ≥10° change in LRT was planned. Lower incisor LRT was not significantly affected by the presence of PRs or differences in WPs. (*Angle Orthod*. 2025;95:12–18.)

KEY WORDS: Clear aligner therapy; Invisalign; Orthodontic treatment outcomes; Torque

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INTRODUCTION

Clear aligner therapy (CAT) is an integral part of modern orthodontics.[1–3] The Invisalign (Align Technology, San Jose, Calif) appliance was the first CAT appliance to use transparent, thermoplastic polymeric materials to fabricate a series of removable aligners using computer-aided design and computer-aided manufacturing (CAD-CAM) technology.[1]

The proprietary online software ClinCheck is the communication interface between the treating clinician and Align Technology.[4] It provides a virtual representation of the treatment plan, progression of tooth movement stages, and a variety of digital data.[5] When the treatment plan is approved by the clinician, a series of aligners is manufactured to enable the prescribed occlusal result to be achieved. One or more additional series of aligners is commonly required to achieve desired occlusal outcomes.[2,4]

Root torque is defined as the buccolingual inclination of the tooth root.[6,7] It was described by Andrews[7] as the “third key of occlusion” and determines the position of the tooth crown. Root torque plays a critical role in orthodontic treatment outcome and posttreatment stability.[7–9] Crown and root movement have also been considered in relation to the center of rotation (Crot) and center of resistance (Cres) of the tooth. Four

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Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Prescription of ≥10° of mandibular central incisor lingual root torque • Complete permanent dentition treated with the Invisalign appliance only • Nonextraction treatment • Completion of the initial series of aligners • Unrestored incisors	• Medical conditions requiring medication that may affect bone metabolism or tooth movement • Noncompliance with prescribed wear protocols as determined by the treating clinician • Intermaxillary elastic wear • Undergoing combined orthodontic and orthognathic surgery • Interproximal reduction • Craniofacial syndromes

movement types have been described. Controlled tipping takes place when the Crot is within 2 mm of the root apex. Uncontrolled tipping occurs when the Crot is within 2 mm of the Cres. Torque happens when the Crot is within 2 mm of the incisal edge. Translation occurs when the Crot is more than six times the alveolar bone height of the original Cres position.

In fixed appliance therapy, changes in root torque principally result from the mechanical interaction between the arch wire and bracket geometries.[6,10] Due to the complex force delivery system of the aligner, however, the ability to achieve the prescribed amount of root torque and, consequently, incisor inclination, has proven to be challenging.[1,11,12]

To overcome the purported biomechanical limitations of CAT in this regard, modifications to aligner characteristics have been introduced.[13] One such modification is the power ridge (PR), which is a localized indentation integrated within the appliance with the aim of enabling greater control of root movement.[1,3]

Despite the popularity of CAT, high-quality evidence is limited regarding its efficacy in achieving planned tooth movements.[14,15] Although several studies[11,16–19] have examined the efficacy of planned changes in maxillary central incisor root torque using CAT, only two[12,20] appear to have focused on planned lower incisor torque changes. While these provided some information regarding lower incisor root movement, uncertainty over the definition of torque and sample sizes reported in the studies has prompted the need for further research.

Therefore, the aim of this study was to determine whether the achieved mandibular central incisor lingual root torque (LRT) changes matched the changes planned via ClinCheck after treatment with an initial series of Invisalign aligners when ≥10° of torque change was planned.

The null hypothesis was that no difference between the planned and the achieved changes in LRT would be found.

MATERIALS AND METHODS

Ethical approval was obtained from the University of Adelaide Human Research Ethics Committee. The sample for this retrospective study was obtained from an independent database of approximately 12,000 patients treated with the Invisalign appliance between 2013 and 2021 by 17 experienced Invisalign provider orthodontists. All patients provided informed consent for their information to be used for research purposes. The entire database was screened to determine the number of patients that satisfied the selection criteria (Table 1).

A planned torque change ≥10° was determined to be moderate to severe, as indicated in a recent similar investigation.[19] Based on previous studies,[21,22] it was ascertained that a sample size of 44 mandibular central incisors was required to identify clinically relevant root movement ≥5°.

The patients that met the inclusion criteria were deidentified, and information regarding their age at the

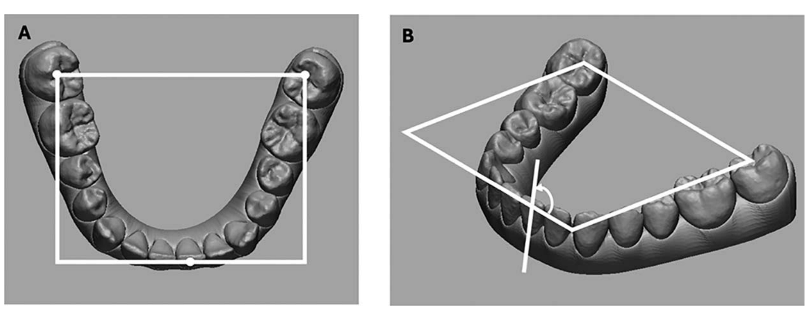

Figure 1. Visual representation of superimposition method. (A) Horizontal reference plane constructed on the digital model of T0 using the most distal right and left mandibular molars and lower left central incisor. (B) The angle formed between the horizontal reference plane and the vertical vector (represents the virtual long axis of the mandibular central incisor) was used to determine the lingual root torque (LRT).

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Table 2. Demographic Statistics According to Subgroups (N = 70 Incisors; 35 Patients)[a]

	Total	Age (y)		Aligners (N)	
Subgroup	No. (%)	Mean ± SD	*P* Value	Mean ± SD	*P* Value
PR					
Y	38 (54.3)	33.3 ± 15.7	.55	41.7 ± 13.2	.85
N	32 (45.7)	31.2 ± 13.3		41.1 ± 13.9	
Sex					
F	48 (68.6)	32.4 ± 14.7	.93	40.1 ± 13.8	.21
M	22 (31.4)	32.1 ± 14.6		44.3 ± 12.3	
WWP					
1 wk	46 (65.7)	34.1 ± 16.8	.08	38.6 ± 12.0	.02
2 wk	24 (34.3)	28.9 ± 7.8		46.8 ± 14.6	

[a] PR indicates power ridge; WWP, weekly wear protocol.

beginning of treatment, sex, number of aligners prescribed in the initial series, aligner wear protocol (WP; either 1 or 2 weeks) and the presence or absence of PRs were recorded on an Excel (Microsoft, Redmond, Wash) spreadsheet.

Digital models representing three time points (pretreatment [T0], the planned treatment outcome [T1], and the achieved outcome at the end of the initial series of aligners [T2]) were imported into the Geomagic Control × (Geomagic US, Research, Triangle Park, NC) metrology software facility in 3D stereolithographic (.STL) file format. Angular and linear measurements were recorded on the models at the different time points.

Superimposition of the three models was performed using the best-fit surface registration with global and fine best fit with a 50-iteration count and sampling ratio of 80%, which was validated in a recent study.[23] A transverse reference plane, as used by Gaddam et al.,[12] was generated on the T0 model (Figure 1A). To determine the amount of LRT, angular measurements were performed between the reference plane and a vertical vector, which was autogenerated by the flood selection tool as per similar studies.[12,19,21,24] The vertical vector representing the virtual long axis of the mandibular central incisors was determined for all three models (Figure 1B).

Orthodontic tooth movement (OTM) can be defined by assessing the position of the Crot of the tooth relative to the Cres and the incisal edge.[21,25] Jiang et al.[25] determined that root torque OTM resulted if the Crot was within 2 mm of the incisal edge. To investigate the accuracy and type of OTM, the position of the Crot relative to the incisal edge, root apex, or the Cres was obtained and categorized according to the criteria described by Smith et al.[21]

Statistical Analysis

Stata 18 (StataCorp. 2023. Stata Statistical Software: Release 18. College Station, TX: StataCorp LLC) and SPSS (version 25; IBM Corp, Armonk, NY) were used for statistical analysis.

To determine the percentage accuracy of the difference between the planned LRT and that achieved, the previously published formula[19,21] was used:

$$\%\,\text{accuracy} = 100\% - \left[\left(\frac{|\,\text{planned} - \text{achieved}\,|}{|\,\text{planned}\,|}\right) \times 100\%\right].$$

The Kolmogorov-Smirnov test indicated normal data distribution. Descriptive statistics were presented

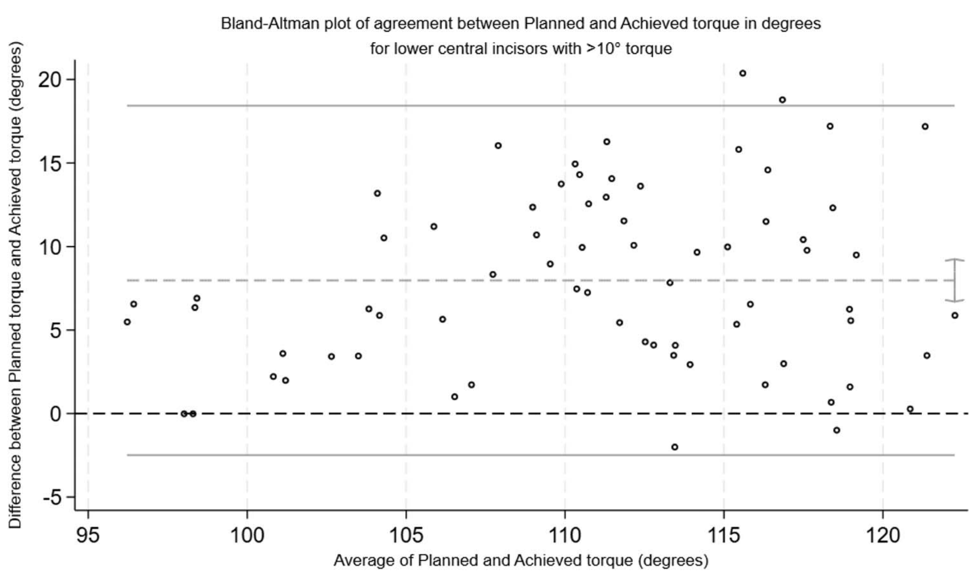

Figure 2. Bland-Altman plot indicating the differences between planned and achieved torque changes. The upper and lower limits of agreement (LoA) are indicated by the solid lines (−2.55 and 18.50). The mean ± SD was 7.97° ± 5.37°.

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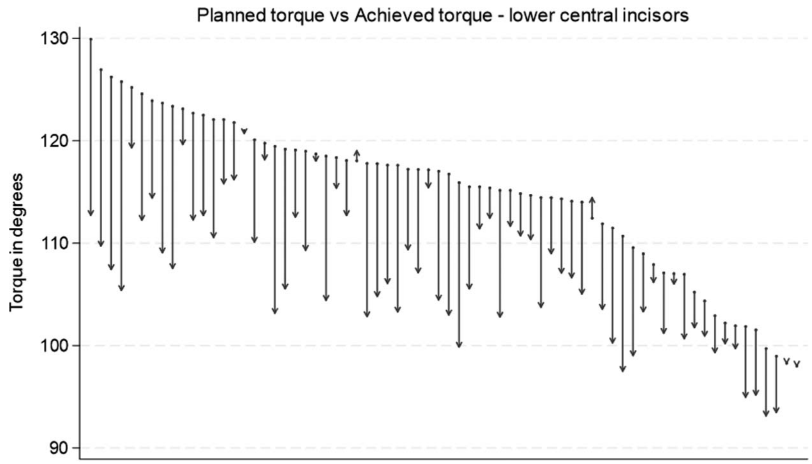

Figure 3. Arrow plot indicating the difference between the planned and achieved torque for each incisor. The planned degree of torque is represented by the dot, and the arrow indicates the direction of the achieved torque. Incisors with under expressed lingual root torque (LRT) are indicated by downward arrows, and the incisors with overexpressed LRT are represented by the upward arrows.

in means and percentages. A Bland-Altman analysis plot was generated to illustrate the level of agreement between planned and achieved LRT changes.

A paired Student's *t*-test was performed to assess the influence that age, sex, WP, number of aligners, and presence of PR had on differences between the planned and achieved measurements. One-way analysis of variance (ANOVA) was performed to determine if a significant difference in accuracy between the presence of PR and WP groups existed. To test if a statistically significant difference between the individual PR and WP groups to the portion of the sample that achieved the planned torque OTM existed, a χ^2 test was conducted.

Linear regression analysis was performed to evaluate the influence of patient and clinical factors on the difference between planned and achieved outcomes. Statistical significance was set at $P < .05$. Clinical significance was set at $\geq 5°$.[19,21] Superimpositions and measurements of the pretreatment, planned, and achieved models of 10 randomly selected patients were repeated 2 weeks apart to calculate intraexaminer and interexaminer reliability.

RESULTS

A total of 35 patients with 70 mandibular central incisors satisfied selection criteria with a mean ± SD patient age of 32.3 ± 14.5 years. Table 2 shows that most patients were female (N = 48; 68.6%). Most central incisors (N = 38; 54.3%) had PRs integrated into the appliance. Most patients were prescribed a 1-week WP (N = 46; 65.7%). The mean ± SD number of aligners prescribed per patient was 41 ± 13.

The overall accuracy of the LRT expression was 58.2%. A Bland-Altman plot indicated that the differences between planned and achieved changes were approximately normally distributed (Figure 2). A cluster toward the lower end of average values and below the mean suggested that a pretreatment lower torque angle led to better accuracy.

Figure 3 illustrates the difference between the planned and achieved LRT changes for each patient.

Underexpression of the planned changes was observed in most incisors (N = 66; 94.3%), overexpression was observed in 2.9% (N = 2), and no difference was noted in two incisors (2.9%). To determine the percentage of incisors that showed a clinically significant shortfall of LRT expression, the level of underexpression was subdivided into increments of 5°. A clinically significant shortfall was observed in 48 incisors (68.6%), most of which under expressed between 10° and 20° (Table 3).

Linear regression analyses indicated no statistically significant effect regarding patient age, sex, WP, or the presence of PR on the difference between the planned and achieved LRT (Table 4).

Figure 4 shows that no difference was found in the accuracy of torque expression between presence and absence of PRs, weekly WP, and combined PR and WP groups.

Table 5 shows that 93.3–100% of mandibular central incisors with LRT or uncontrolled tipping movements planned achieved that OTM type.

Table 3. Breakdown of Clinically Significant Torque Under Expression per Mandibular Central Incisor

Shortfall	Mandibular Central Incisors, No. (%)
<5°	22 (31.4)
5–10°	23 (32.9)*
10–20°	24 (34.3)*
20–25°	1 (1.4)*

* Clinically significant.

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Table 4. Linear Regression Analysis of Discrepancy Between Planned and Achieved Torque of Mandibular Central Incisors Using Selected Patient and Clinical Factors[a]

Variable	Unadjusted Effect (95% CI)	*P* Value
Patient age, y[b]	−0.02 (−0.13, 0.09)	.68
Male sex[c]	−0.38 (−4.21, 3.44)	.84
2-week frequency of wear[d]	0.00 (−4.11, 4.11)	1.00
Number of aligners[e]	0.16 (0.05, 0.26)	<.01
Presence of PR[f]	−0.47 (−4.10, 3.15)	.79

[a] CI indicates confidence interval; WP, wear protocol; PR, power ridge.

[b] Effect estimate is the mean change in discrepancy associated with a 1-year increase in patient age.

[c] The reference category is female sex. Effect estimate is the mean difference in discrepancy for male patients compared with female patients.

[d] The reference category is 1-WP. Effect estimate is the mean difference in discrepancy for 2-WP compared with 1-WP.

[e] Effect estimate is the mean change in discrepancy associated with a 1-unit increase in number of aligners.

[f] The reference category is no PR. Effect estimate is the mean difference in discrepancy when PR is present compared with absent.

A trend toward greater accuracy was observed in those prescribed PRs, the 2-week WP, and the combined 2-week WP/PRs groups. However, this was not statistically significant ($F = 0.92$, $P = .44$).

ICC scores between 0.91 and 0.95 were achieved, indicating excellent reliability.

DISCUSSION

We are the first to investigate the efficacy of lower central incisor moderate to severe LRT changes using the Invisalign appliance. The findings indicated that the achieved changes were less than 60% of those planned and that WP and the presence of PRs made little difference to the accuracy of changes. The null hypothesis was rejected. The findings provide clinically relevant data concerning the management of lower central incisors, requiring considerable LRT changes with the Invisalign appliance.

The overall accuracy of torque expression was 58.2% of the planned change in LRT in lower central incisors. This reflected the challenges observed in fixed appliance therapy regarding the delivery of optimal torque.[26] With clinical significance defined as a ≥5° difference between planned and achieved outcomes in the present study, approximately 70% of the incisors showed a clinically significant shortfall of the planned changes. Most investigations regarding CAT torque efficacy focus on upper incisor root torque. However, authors of two studies[12,20] have examined the efficacy of CAT in producing desired torque changes in lower incisors. The current findings indicated greater efficacy than the landmark prospective study by Kravitz et al.,[17] who reported an overall mean accuracy of 41%. That study, however, was carried out before the introduction of the currently used SmartTrack material. Interestingly, Gaddam et al.[12] demonstrated that the planned root torque changes were more reliably expressed in the lower incisors than the upper incisors, with a mean accuracy of 64.7% for lower labial crown torque being recorded. This was reportedly due to incisor proclination resulting from leveling of the curve of Spee. However, the definition of torque in that study was based on the labiolingual position of the crown, and the sample was subdivided depending on the direction of overexpression

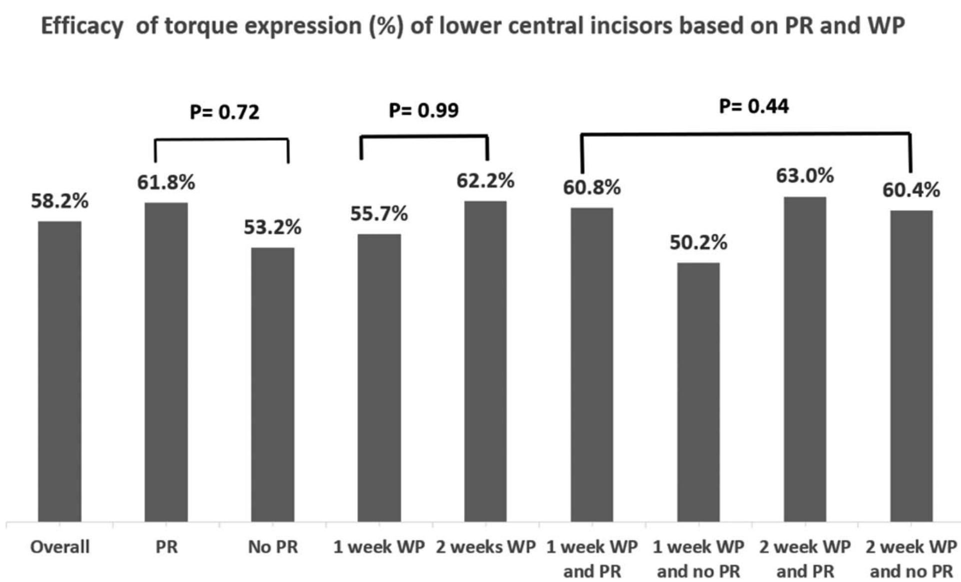

Figure 4. Accuracy of LRT expression between presence and absence of PR, weekly WP and combined PR and WP groups. LRT indicates lingual root torque; PR, power ridge; WP, wear protocol; statistical significance = $P < .05$.

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Table 5. Planned and Achieved OTM According to PR and WWP Factors[a]

Planned OTM		Achieved OTM		PR		WWP	
Type	No. (%)	Type	No. (%)	Yes (N = 39)	No (N = 31)	1-weekly (N = 46)	2-weekly (N = 24)
Torque	15 (21.4)	Torque	14 (93.3)	6	8	10	4
		Uncontrolled tip	0	0	0	0	0
		Controlled tip	1 (6.7)	1	0	1	0
Uncontrolled tip	53 (75.7)	Torque	12 (22.6)	6	6	7	5
		Uncontrolled tip	40 (75.5)	24	16	25	15
		Controlled tip	1 (2)	1	0	1	0
Controlled tip	2 (2.9)	Torque	0	0	0	0	0
		Uncontrolled tip	0	0	0	0	0
		Controlled tip	2 (100)	1	1	2	0

[a] OTM indicates orthodontic tooth movement; PR, power ridge; WWP, weekly wear protocol.

or underexpression. By contrast, 86.1% of the planned lower incisor torque changes was achieved in a 2017 study.[20] In that study, however, the authors used a different CAT system, and the torque movement evaluated was not clearly defined.

Linear regression analysis was conducted to determine the influence of patient and clinical factors. Although a trend toward greater accuracy was observed in those that had PRs, the 2-week WP, and the combined 2-week WP/PRs groups, one-way ANOVA indicated that this was not significant. These findings regarding WPs were like those in the study by Smith et al.[21] concerning lower incisor mesiodistal root tip. However, in the present study, we suggest that an increased number of prescribed aligners increased the accuracy of torque expression. Further research is required to explore whether more frequent aligner change may improve the efficacy of planned torque changes.[1]

The retrospective nature of the study risks selection bias. However, this was minimized by screening all patients from a very large database and adopting strict inclusion criteria. Although the criteria aimed to reduce the effect of potential confounding factors, any rotational corrections, the initial amount of spacing, or crowding present in which transverse corrections were required, as well as the underestimation of the mesiodistal widths of the teeth by ClinCheck, may favor forces to be directed more lingually or labially. Additionally, the findings of the present study are relevant to the initial series of Invisalign aligners and are not applicable to additional series of Invisalign aligners or other CAT brands.

CONCLUSIONS

- Achieved LRT changes in mandibular central incisors were 58.2% of those planned when $\geq$10° of change in LRT was planned with an initial series of Invisalign aligners.
- Most incisors (68.6%) showed a clinically significant ($\geq$5°) underexpression of their planned LRT changes.
- The presence/absence of PRs, 1-weekly/2-weekly WPs, and combined WP and PR groups made little difference to the accuracy of planned LRT changes.
- An increased number of prescribed aligners appeared to increase the accuracy of LRT expression.

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