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ORIGINAL RESEARCH

Prescription reliability of maxillary tooth movements by an orthodontic clear aligner system in children: a preliminary retrospective study

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Abstract

Background: The Dio Ortho navi clear aligner system was recently introduced to the market. This study aimed to confirm the reliability of the Dio Ortho navi clear aligner system by assessing the consistency between actual and predicted orthodontic tooth movements. **Methods**: Mixed-dentition and permanent-dentition patients were included. Sequential individualized orthodontic tooth movements were prescribed and recorded as digital images. Intraoral scans were performed at the corresponding observation periods: before treatment (T_0), after 20 weeks (T_1), and at the end of treatment (T_2). Linear measurements were made, including changes in the arch width, tooth position of the maxillary permanent first incisors and permanent first molars, and torque of the maxillary permanent first incisors. Discrepancies between predicted and observed results were calculated. Superimposition between the predicted and achieved dental arches was performed, and the root mean square (RMS) values for the entire tooth surfaces were calculated at T_2. **Results**: No significant differences in the linear discrepancies were observed between two groups ($p > 0.05$), except for intermolar width changes at T_1 and torque changes. Most tooth position discrepancies ranged within 0.5 mm. The mean RMS values were 0.77 ± 0.20 mm in the mixed-dentition group and 0.92 ± 0.29 mm in the permanent-dentition group with no significant differences ($p > 0.05$). **Conclusions**: Within the limits of this study, no significant differences in the reliability of orthodontic tooth movement were observed between patients with mixed and permanent dentition. This finding suggests that the Dio Ortho navi clear aligner can be a reliable treatment option for clear orthodontic aligners.

Keywords

Children; Clear orthodontic aligner; Digital dentistry; Orthodontic appliance; Reliability

1. Introduction

Fixed orthodontic treatment involves bonding brackets to the tooth and connecting them to archwires to correct tooth misalignment and occlusion [1]. However, brackets and archwires can create an environment where maintaining oral hygiene is challenging, resulting in plaque accumulation [2]. White spot lesions around brackets are common complications of fixed orthodontic treatment, resulting from an increase in the number of acid-producing bacteria in the oral cavity [3]. The incidence of white spot lesions is reported to be approximately 36–79.3% in patients who undergo fixed orthodontic treatment [4]. Studies have also reported that adolescents are more susceptible to lesion development [4]. Consequently, lesion formation may be a limitation of fixed orthodontic treatment in children and adolescents, especially given the growing attention to appearance and its impact on their psychological well-being [5].

In 1999, the first clear aligner, called Invisalign® (Align Technology, Santa Clara, CA, USA), was introduced [6]. Since then, various commercial clear aligner systems have been developed as alternatives to fixed orthodontic treatment [7]. These systems have become popular because they are less painful [8], facilitate maintenance of oral hygiene [9] and are more esthetically acceptable. In addition, these systems incorporate programmed, individualized tooth movements to induce actual orthodontic tooth movements [10]. However, studies on the predictability of tooth movement according to the dentition stage are limited and conflicts between the predicted and actual tooth movements are an area of concern [11]. Previous studies on the predictability of tooth movement with Invisalign® have demonstrated actual tooth movement is often less predicted [12, 13]. Another study showed that the predictability of Invisalign® varied by the type of tooth movement. The study concluded that the predictability was highest for vestibulo/lingual crown tipping, followed by intrusion with rotation being the least predictable [14]. These findings were also observed with other clear aligner system, such as the F22 aligners, whose predictability of tooth movement was reported to be 73.6%. Specifically, tipping movement was acceptably predictable, while rotation was not [15]. Therefore, assessing the accuracy of orthodontic tooth movement is crucial to confirm the treatment efficacy of clear aligner systems.

The Dio Ortho navi clear aligner (Dio co., Busan, Korea), introduced in 2020, features a unique system that resets the prescription of orthodontic tooth movement every 10 weeks to compensate for any discrepancy between the actual and predicted tooth movements. This study aimed to assess the consistency between predicted and achieved orthodontic tooth movements according to the dentition stage when using the Dio Ortho navi system. The null hypothesis of this study posited significant differences in the consistency of orthodontic tooth movement according to dentition stage.

2. Materials and methods

2.1 Study design and treatment procedure

This retrospective study, performed by the ethics approval, included patients aged 7–13 years who visited the Department of Pediatric Dentistry at two university hospitals between 2022 and 2023. Only patients who underwent orthodontic treatment with Dio Ortho navi clear aligners for tooth alignment and/or decrowding with tooth extraction were included. Patients with genetic disorders or significant medical histories were excluded. Finally, 18 patients were selected and divided into two groups: the mixed-dentition group (n = 8) and the permanent-dentition group (n = 10). Due to the preliminary nature of this study, a sample size of 18 was simply determined from the pool of patients who had completed the orthodontic treatment with Dio Ortho navi clear aligners. Patients with any primary tooth in their maxillary dentition were included in the mixed-dentition group, and patients with no primary teeth were included in the permanent-dentition group. The characteristics of the patients are shown in Table 1. Angle classification was determined by anteroposterior relationship of the intercupation between the maxillary and mandibular first molars [16]. The degree of crowding was defined based on the arch length discrepancy: a space deficiency of 1–3 mm was considered mild, 4–6 mm as moderate, and more than 6 mm as severe. According to the manufacturer's recommendations, a sequential prescription for orthodontic tooth movement was planned as follows: (i) individualized 3-dimensional movement of each tooth, (ii) arch expansion, and (iii) interproximal reduction. Next, a digitized tooth model incorporating the prescription was created and saved in standard triangulated language (STL) file format for the analysis of the predicted tooth movement.

All patients were instructed to wear the aligners for more than 12 hours per day and to change the aligners at 1-week intervals. Every 5 weeks, patients visited the department where pediatric dentists checked the fit of the aligners and the attachment conditions. If any attachment was lost or detached, it was replaced. To assess tooth movement, digital impressions were acquired using an intraoral scanner (TRIOS4; 3Shape A/S, Copenhagen, Denmark) and saved in STL file format. Impressions were recorded before treatment (T_0), after 20 weeks of treatment (T_1), and at the end of treatment (T_2).

2.2 Assessment of orthodontic tooth movements

Two types of digitalized maxillary tooth models (predicted and achieved) were imported into GOM Inspect 2018 software (GOM GmbH, Braunschweig, LS, Germany), and the following measurements were performed: (i) arch width, (ii) position of the maxillary first incisors and first molars, and (iii) torque of the maxillary first incisors. Measurements were performed by two independent investigators at three time points: before treatment (T_0), after 20 weeks (T_1), and at the end of treatment (T_2).

Arch width was measured as the distance between the buccal cusps of the primary first molars or permanent first premolars and the distance between the mesiobuccal cusps of the permanent first molars (Fig. 1A). The position of the first incisors was measured as the distance to the perpendicular line penetrating the midpoint of the incisive papilla, whereas that of the first molars was measured as the distance to the vertical line through the midline of the incisive papilla (Fig. 1B,C). Torque was assessed by measuring the angle formed between the first incisor and the reference plane (Fig. 2). The reference plane was defined as the plane passing through a tripod of points: the contact point between the incisal edges of the maxillary first incisors and the cusp tips of the mesiobuccal cusps of the maxillary first molars [17].

After the measurements were completed, changes were calculated as follows: ΔPT_1: changes in the measurement between T_1 and T_0 in predicted tooth movement models; ΔPT_2: changes in the measurement between T_2 and T_0 in predicted tooth movement models; ΔAT_1: changes in the measurement between T_1 and T_0 in achieved tooth movement models; ΔAT_2: changes in the measurement between T_2 and T_0 in achieved tooth movement models. Then, the discrepancy between the predicted and actual models at each time point was calculated.

2.3 Reliability assessment over the entire tooth surface

To assess the discrepancy between the predicted and achieved tooth movement over the entire tooth surfaces, the digitized tooth models at T_2 were imported into the GOM Inspection 2018 software, and the two models were superimposed using the pre-alignment command. All points on the surface of each tooth indicated as small triangles, were used to measure the distance from the superimposed surface [18]. The closest distance from each point to the tooth surface was automatically calculated using surface comparison. The root mean square (RMS) value was calculated by counting the number of color-coded triangles. Finally, the two superimposed tooth surfaces were visualized as a color-coded map: red indicates a discrepancy of more than 1.6 mm, blue shows a discrepancy of more than −1.6 mm, and green indicates a discrepancy within −0.4 to 0.4 mm when comparing the two tooth models.

TABLE 1. Characteristics of the patients in this study.

	Mixed dentition N (%)	Permanent dentition N (%)
Sex		
Male	3 (37.5%)	4 (40.0%)
Female	5 (62.5%)	6 (60.0%)
Interproximal stripping	2 (25.0%)	0 (0.0%)
Angle classification		
Class I	5 (62.5%)	6 (60.0%)
Class II	1 (12.5%)	1 (10.0%)
Class III	2 (25.0%)	3 (30.0%)
Crowding		
Mild	4 (50.0%)	6 (60.0%)
Moderate	3 (37.5%)	3 (30.0%)
Severe	1 (12.5%)	1 (10.0%)

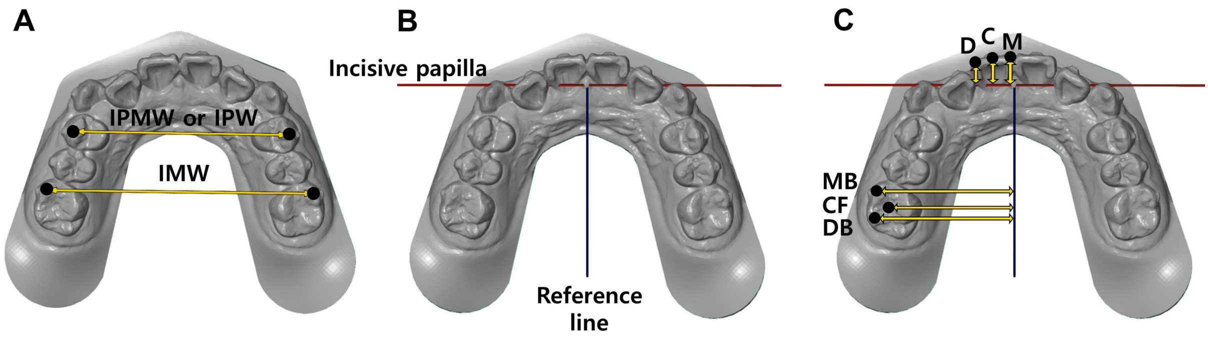

FIGURE 1. Arch width and tooth position. (A) Arch widths. The widths were calculated by measuring interprimary molar width (IPMW) or interpremolar width (IPW) and intermolar width (IMW). (B) Establishment of the reference lines for tooth position. A vertical line was drawn through the midline of the incisal papilla (black line) and a perpendicular line to the black line (red line) was drawn penetrating the center of the incisal papilla. (C) Position of maxillary first incisors and first molars. The distance between the tooth and the reference line was measured. For each tooth, the measurement was performed at 3 points. M, mesial point of incisal edge; C, central point of incisal edge; D, distal point of incisal edge; MB, mesiobuccal cusp tip; CF, central fossa; DB, distobuccal cusp tip.

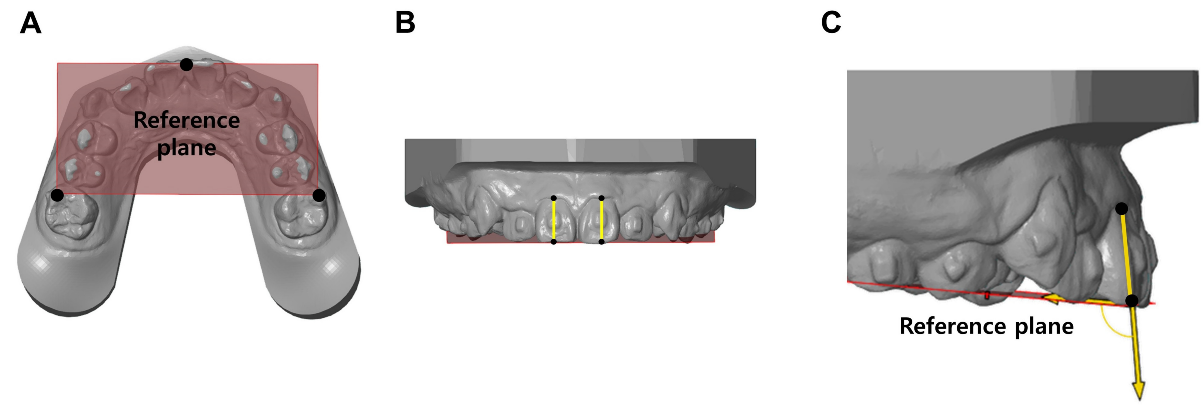

FIGURE 2. Torque of maxillary first incisors. (A) Establishment of the reference plane. The plane was set as a tripod of points from the contact point between the incisal edges of maxillary first incisors and the cusp tips of the mesiobuccal cusps of the maxillary first molars. (B) Establishment of the reference line. The line (yellow line) was drawn from the midpoint of the cervical margin to the midpoint of the incisal edge of the maxillary first incisors. (C) Torque measurement. Torque was measured as the angle between the reference line and plane.

2.4 Statistical analysis

All data were analyzed using IBM SPSS Statistics 20 (IBM Corp., Armonk, NY, USA). To confirm the interobserver reliability of the measurements, intraclass coefficient (ICC) values were calculated and the resulting values ranged from 0.88 to 1.00, indicating a high level of consistency between the examiners. The results were statistically analyzed using the Mann-Whitney test ($p < 0.05$) or the independent t-test ($p < 0.05$) based on the findings from the normality test.

3. Results

Table 2 shows the discrepancies between the predicted and achieved tooth movement changes according to dentition type. At T_1, the achieved changes in arch width and tooth position in the permanent-dentition group showed overcorrection compared to the predicted values, whereas the changes in the mixed-dentition group did not. However, no significant differences in achieved *vs.* predicted discrepancies were observed between the mixed- and permanent-dentition groups, except for the intermolar width change and #21 torque change ($p < 0.05$). At T_2, there were no significant differences in the discrepancy between achieved and predicted values between the two groups, except for #21 torque change (2.42 ± 2.43° *vs.* 0.13 ± 1.97° for mixed dentition *vs.* permanent dentition, $p < 0.05$).

Fig. 3 presents a boxplot of RMS values for the entire tooth surface. Regarding the reliability of orthodontic tooth movement over entire tooth surfaces, the average RMS was 0.85 ± 0.26 mm in all patients. The average RMS values were 0.77 ± 0.20 mm in the mixed-dentition group and 0.92 ± 0.29 mm in the permanent-dentition group with no statistically significant differences ($p > 0.05$). Representative superimposed images of the two groups are shown in Fig. 4, with original images provided in **Supplementary Figs. 1,2**.

4. Discussion

This retrospective study evaluated the reliability of orthodontic tooth movement using the Dio Ortho navi clear aligner system according to the dentition stage. The null hypothesis that there was a difference in consistency of orthodontic tooth movement depending on the dentition, was rejected. No significant differences between the mixed and permanent dentitions were observed, except for intermolar width changes at the early stage.

The change in the arch width achieved at T_1 in the mixed-dentition group was less than the predicted change. This result

TABLE 2. Discrepancy between predicted and achieved tooth models in arch width and tooth position changes during orthodontic clear aligner treatment.

	$\Delta AT_1 - \Delta PT_1$		$\Delta AT_2 - \Delta PT_2$	
	Mixed dentition	Permanent dentition	Mixed dentition	Permanent dentition
Width changes (mm)				
IPW	-1.05 ± 1.17^A	0.21 ± 1.56^A	0.19 ± 2.39^a	-0.22 ± 2.92^a
IMW	-1.87 ± 1.51^A	0.71 ± 1.77^B	0.10 ± 2.86^a	-0.03 ± 3.43^a
Tooth position changes (mm)				
#11D	-0.18 ± 0.99^A	0.08 ± 0.37^A	0.67 ± 1.28^a	0.04 ± 0.91^a
#11C	-0.21 ± 0.99^A	0.09 ± 0.34^A	0.61 ± 1.08^a	0.02 ± 0.78^a
#11M	-0.23 ± 0.94^A	0.06 ± 0.36^A	0.49 ± 1.03^a	0.05 ± 0.74^a
#21D	-0.25 ± 0.77^A	0.21 ± 0.33^A	0.39 ± 0.88^a	-0.02 ± 0.89^a
#21C	-0.13 ± 1.02^A	0.16 ± 0.36^A	0.73 ± 1.27^a	-0.01 ± 0.88^a
#21M	-0.31 ± 1.06^A	0.02 ± 0.21^A	0.51 ± 0.95^a	-0.02 ± 0.82^a
#16MB	-1.16 ± 1.07^A	0.25 ± 0.71^A	-0.12 ± 1.78^a	-0.05 ± 1.82^a
#16CF	-0.72 ± 1.12^A	0.19 ± 0.67^A	0.00 ± 1.75^a	-0.12 ± 1.66^a
#16DB	-0.79 ± 1.23^A	0.42 ± 0.80^A	0.18 ± 2.04^a	-0.06 ± 1.82^a
#26MB	-0.67 ± 0.73^A	0.45 ± 1.31^A	0.22 ± 1.78^a	0.23 ± 2.05^a
#26CF	-1.05 ± 1.23^A	0.54 ± 1.35^A	0.32 ± 1.50^a	0.41 ± 1.74^a
#26DB	-0.36 ± 1.48^A	0.59 ± 1.46^A	0.31 ± 1.69^a	0.45 ± 2.08^a
Torque changes (°)				
#11	1.50 ± 2.97^A	-0.51 ± 1.21^A	1.52 ± 1.93^a	0.37 ± 1.58^a
#21	2.45 ± 4.05^A	-0.10 ± 2.29^B	2.42 ± 2.43^a	0.13 ± 1.97^b

Different uppercase letters indicate statistical differences by dentition stage at T_1, and different lowercase letters indicate statistical differences by dentition stage at T_2. ($p < 0.05$). IPW, interpremolar width; IMW, intermolar width; D, distal point of incisal edge; C, central point of incisal edge; M, mesial point of incisal edge; MB, mesiobuccal cusp tip; CF, central fossa; DB, distobuccal cusp tip.

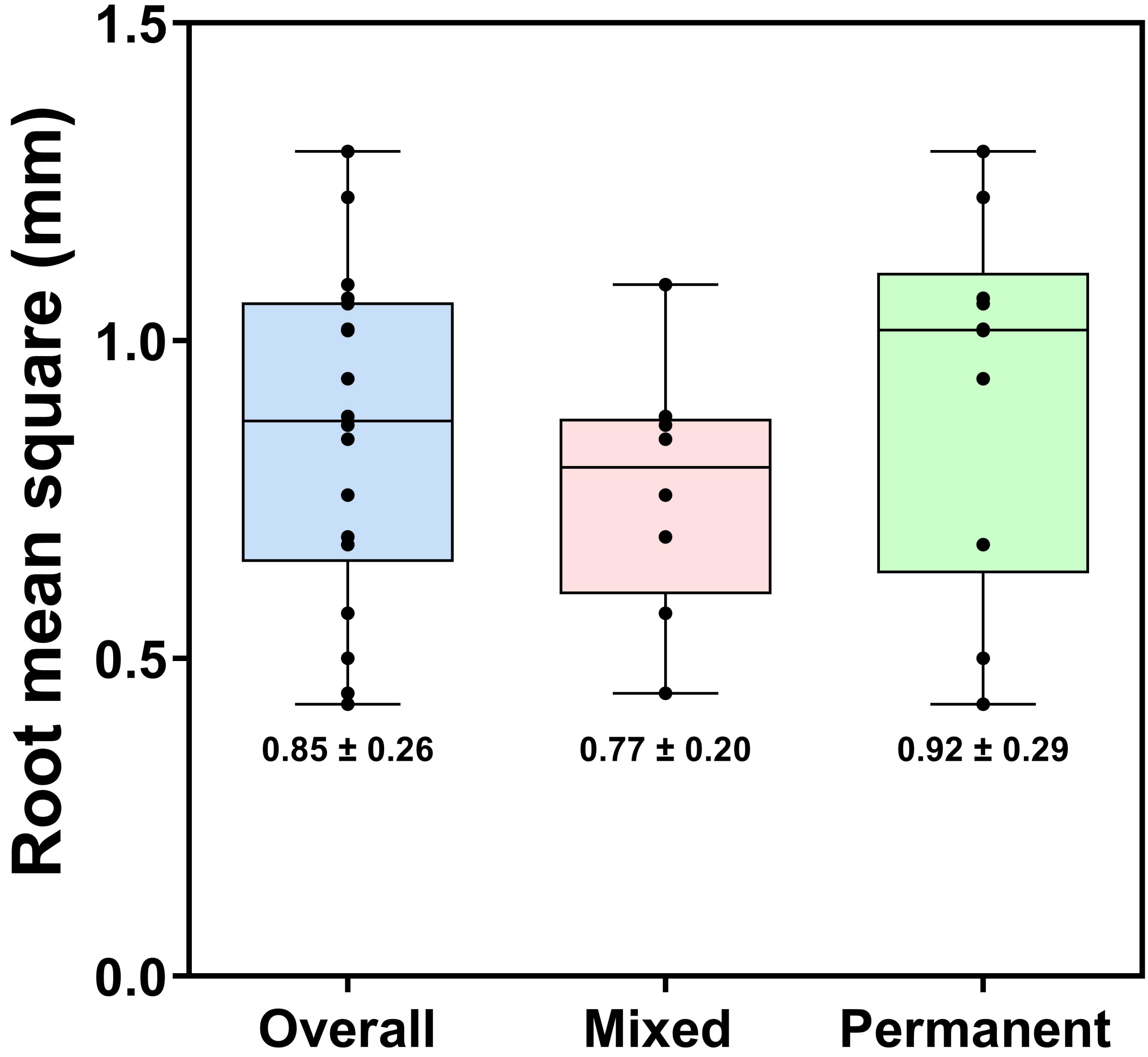

FIGURE 3. Average root mean square (RMS) measurement between the predicted and achieved tooth models over the entire tooth surfaces. The lines in the box represent the median values in the quantiles. The dots represent the RMS values for each patient. Note that no significant differences in average RMS values were found between two groups (mixed dentition *vs.* permanent dentition; $p > 0.05$).

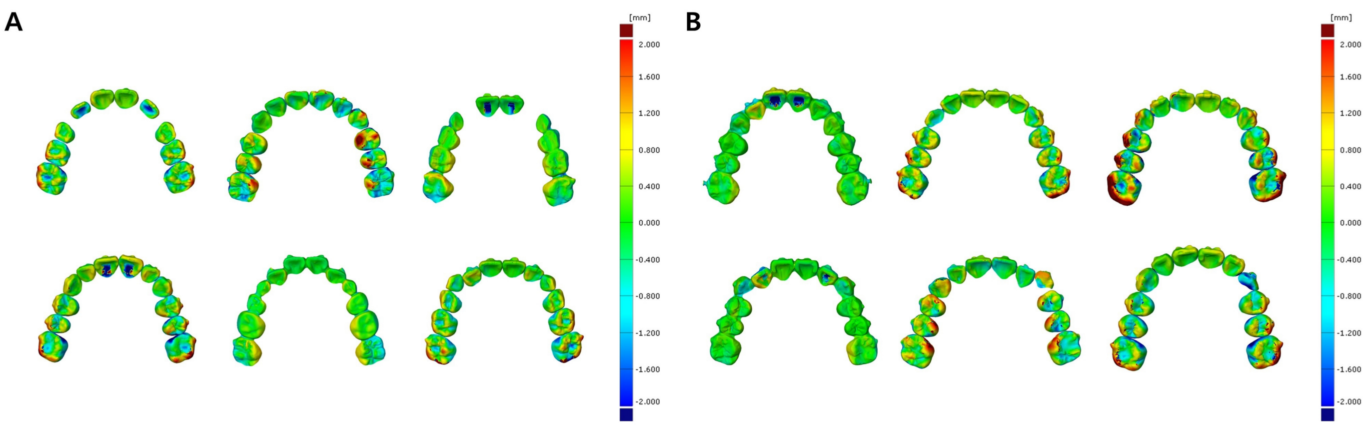

FIGURE 4. The discrepancy between predicted and achieved tooth models. (A) Mixed-dentition group. (B) Permanent-dentition group. The amount of discrepancy is presented by color-coded mapping. Typical images are shown, and some images are hidden.

is consistent with previous studies showing that the achieved maxillary arch expansion was less than that prescribed by the Invisalign® First system [19]. In this study, the observed discrepancy in the arch-width change between the permanent first molars was more pronounced than that between the primary first molars/permanent first premolars. A previous study demonstrated that this phenomenon may be due to differences in the anchor values [19], as the value increases when the tooth is positioned posteriorly, inducing less orthodontic tooth movement by the applied force. In contrast, the change in arch width observed in the permanent-dentition group at this stage was greater than that predicted in the mixed-dentition group. Although this result is not consistent with previous studies [20], the discrepancies in this study were within 0.5 mm, which is clinically acceptable [21]. Similar values for the predictability of transverse changes were also observed in adult patients treated with clear aligners when compared based on absolute values [22]. These findings suggest that clear aligner therapy may be a reliable treatment option in pediatric patients. The difference in the amount of planned tooth movement per patient may have contributed to these conflicting results [23]. The fact that the Dio Ortho navi clear aligner system resets orthodontic prescriptions every 10 weeks may also explain the conflicts. Considering the absolute values of the discrepancy, it was expected that the achieved change would be more predictable at T_2 in both dentition groups. This finding is consistent with studies showing that the movement of teeth in the later stages of orthodontic clear aligner treatment was closer to planned position than that in the earlier stages [24].

Changes in tooth position were not significantly different between the mixed- and permanent-dentition groups. In this study, most of the tooth-position discrepancies were within 0.5 mm, similar to those observed in previous studies [25, 26]. Grünheid *et al.* [27] suggested that tooth-position discrepancies greater than 0.5 mm are clinically relevant in orthodontic clear aligner treatment because they can affect the alignment of contact points and marginal ridges. A previous cone beam computed tomography study reported that the buccolingual discrepancy in the central fossa position of the maxillary first molars after Invisalign® treatment was −0.72 to 0.49 mm [25]. In this study, at the T_1 stage, both groups showed a tendency for predictability to decrease toward the posterior teeth, which is consistent with previous research findings [12]. This shows the same result as width change. However, an opposite trend was observed in the later stages of treatment, with a tendency for predictability to decrease in the anterior teeth of the mixed dentition group. This phenomenon occurs because tooth eruption and changes during the mixed dentition period make it difficult to predict the later stages of orthodontic treatment.

Angular values ranging from −2° to 2° are believed to be clinically significant in orthodontic clear aligner treatment [27]. Our results showed no significant differences in the torque discrepancies between the mixed- and permanent-dentition groups, except for #21 torque. Notably, a greater than 2° torque discrepancy was observed in the mixed-dentition group. This finding could be attributed to directional variations in predicted tooth movement in patients with mixed dentition. A retrospective study found that the incisor torque discrepancy after Invisalign® treatment was from −3.4° to 9° and demonstrated that the intensity of incisor torque was differentially expressed depending on the labiolingual direction of prescribed tooth movement [28]. Furthermore, this finding could be related to the unique characteristics of patients with mixed dentition who have relatively short clinical crowns and undergo complex-dentition transitions [29].

RMS values are typically used to calculate the average discrepancy when presented in the form of signed values [30]. In this study, the average RMS value over the entire tooth surface was 0.85 ± 0.26 mm in all patients after Dio Ortho navi clear aligner treatment, and the differences in the average RMS values were not statistically significant between the two groups (0.77 ± 0.20 mm in the mixed-dentition group and 0.92 ± 0.29 mm in the permanent-dentition group). A previous study evaluating 22 dental arches treated with directly-printed clear aligners found that the mean discrepancy between the achieved and predicted arches was 5.1 ± 5.1 mm with an accuracy of approximately 54% [31]. Similarly, another study reported an average discrepancy of 0.73 ± 0.44 mm in all teeth between simulated and actual orthodontic outcomes using the Incognito Lite appliance system [32]. Considering these findings, orthodontic tooth movement by the Dio Ortho navi clear aligner can be predicted.

This retrospective study had several limitations. First, the sample size was relatively small because the Dio Ortho navi clear aligner system was only recently introduced. Although all patients treated within the defined time period were included, the final sample size remained limited. Therefore, the generalizability of the findings may be limited due to the small sample size, which results in low statistical power. Further studies with prospective designs or larger sample sizes are warranted. Second, the assessment of orthodontic tooth movement was simplified. Recent studies have suggested that horizontal tooth movement is more predictable than vertical tooth movement with clear aligner system [33]. Since this study only evaluated discrepancies in horizontal tooth movement, it was not possible to compare them with vertical tooth movement. Finally, the effects of interproximal stripping on orthodontic tooth movement were not considered. In the future, additional studies should be conducted to confirm the present findings.

5. Conclusions

In conclusion, this study evaluated the reliability of orthodontic tooth movement after treatment with the Dio Ortho navi clear aligner and found an average discrepancy of 0.85 mm between achieved and predicted tooth movement. It was also observed that the difference between predicted and achieved tooth movement tended to decrease in the later stages of treatment compared to the initial stages. This finding indicates that the mechanism of the Dio Ortho navi clear aligner, which resets every 10 weeks, can contribute to improved reliability over time, suggesting that orthodontic treatment with this system is reliable regardless of dentition type.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

JS and OHN—designed the research study. JRY, SR and JSL—performed the research. EL—provided help and advice on the research. JSL—contributed the resources. JRY and OHN—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted following the Declaration of Helsinki. The study protocol was reviewed and approved by the Institutional Review Board of the Kyung Hee University Dental Hospital, Seoul, Korea (KH-DT24018) and Pusan National University Dental Hospital (PNUDH-2024-08-006). Informed consent was obtained from the parents/guardians of patients.

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CONFLICT OF INTEREST

We disclose that Jang Sun Lee is employed by the company that manufactures the Dio Ortho navi clear aligner system. This relationship should be considered when interpreting the findings.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2006248308970799104/attachment/Supplementary%20material.docx.

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