Original Article

Usefulness of an artificial intelligence–assisted indirect bonding method for optimizing orthodontic bracket positioning

Petra C. Bachour[a]; Robert T. Klabunde[b]; Thorsten Grünheid[c]

ABSTRACT

Objectives: To compare the bracket positioning accuracy of a traditional and an artificial intelligence (AI)-assisted digital indirect bonding (IDB) method to explore the current usefulness of AI for optimizing orthodontic bracket positioning.

Materials and Methods: Twenty-five clinicians positioned brackets using traditional and AI-assisted digital IDB methods. Bracket positioning differences were quantified using digital superimposition of bracket setups and compared with an optimal setup. A total of 1800 bracket positioning differences were evaluated. One-tailed *t*-tests were used to determine whether these differences were within limits of 0.5 mm in mesial-distal and occlusal-gingival dimensions and within 2° for tip.

Results: Overall mean bracket position differences between the traditional and digital setups were 0.28 mm for mesial-distal placement and 0.32 mm for occlusal-gingival placement; both were significantly below the 0.5-mm limit. In contrast, differences in tip were 3.4°, which was significantly greater than the 2° limit. Comparisons with an optimal setup showed overall statistically significant differences in mean bracket positioning for tip but not for the mesial-distal or occlusal-gingival measurements for both the traditional and AI-assisted digital IDB methods. However, the digital method was more accurate for bracket tip.

Conclusions: Bracket positioning is consistent and highly accurate in linear dimensions with both traditional and digital IDB methods; however, AI may be useful for improving accuracy of bracket angulation. Clinicians who currently use traditional IDB methods may adopt AI-assisted digital IDB without compromising bracket positioning accuracy. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: 3D technologies; Accuracy; Artificial intelligence; Digital workflow; Indirect bonding

INTRODUCTION

Indirect bonding (IDB) has undergone significant improvements since it was first introduced in 1972.[1] The conventional IDB technique involves manually positioning brackets on a stone or resin model of the patient's teeth, followed by laboratory fabrication of transfer trays using silicone-based materials and/or vacuum-formed materials.[2,3] Facilitated by intraoral scanning, three-dimensional (3D) printing, and virtual treatment planning, digital methods for IDB have been developed.[4,5] In digital IDB, software is used to digitally position brackets on virtual models of the teeth. A transfer tray can be designed virtually and directly 3D printed with no physical model as an intermediary.[6] Digital IDB promises all the advantages of traditional IDB in addition to a completely digital workflow, computer-aided bracket positioning, and standardization of tray fabrication.[4,5]

Recently, artificial intelligence (AI) has emerged in orthodontics.[7] For diagnostics, AI can assist orthodontists with analysis of clinical imagery, such as automated landmark detection in lateral cephalograms.[8] For treatment planning, AI can provide decision support needed for extractions or orthognathic surgery. For clinical practice, the technology can be used in AI-driven remote monitoring and AI-assisted IDB methods.[9]

Notably, only a few AI applications in orthodontics have reached full clinical maturity,[10] and real-world evaluation is needed before AI is implemented into the orthodontic workflow. For this reason, in the present study, we compared the bracket positioning accuracy of

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traditional and AI-assisted digital IDB methods to explore the current usefulness of AI for optimizing orthodontic bracket positioning.

MATERIALS AND METHODS

Approval was obtained from the Institutional Review Board at the University of Minnesota (STUDY00019022). Informed consent was obtained from all study participants. Participants were a convenience sample of orthodontists and senior orthodontic residents who were willing to participate. Inclusion criteria were at least 1 year of training in an accredited orthodontic program and experience with IDB. Exclusion criteria were less than 1 year of orthodontic training. The final sample consisted of 25 participants (20 orthodontists, 5 orthodontic residents; 12 males, 13 females; age $= 45.0 \pm 14.6$ years).

Each participant positioned brackets on a dental model using a traditional, physical cast-based IDB method and a digital, virtual cast-based method separated by a 2-week washout period. The order was randomized for each participant. Brackets were placed on all teeth, including first molars. After bracket positioning with both methods was complete, participants were asked to fill out a survey regarding their years of clinical experience, routine use of and comfort level with IDB, and the number of cases they had bonded using traditional and digital IDB methods.

The pretreatment model of a patient with complete permanent dentition; Class I molar relationship; less than 7 mm of crowding per arch; no dental restorations, crown abnormalities or fractures, severe rotations, or deep anterior overbite impeding ideal bracket positioning was used for all study procedures. The panoramic radiograph and clinical photographs of the patient were anonymized and made available to the participants during bracket positioning.

For the traditional IDB method, stereolithography (STL) files of the model were 3D-printed (Form 2, Form-Labs, Boston, Mass) with a 25-μm layer thickness. Participants were provided with a set of bracket placement instruments, bracket height gauges, and adhesive (Transbond XT, Solventum, Saint Paul, Minn) and were asked to place conventional metal brackets and molar tubes (3M Victory Series, Solventum) in ideal positions on all teeth except second molars. After light curing, the models were scanned (iTero element, Align Technology, San Jose, Calif) and the resulting digital model exported in STL format as *traditional setup*.

For the digital IDB method, the model was imported into DIBS AI software (OrthoSelect, American Fork, Utah). Digital versions of the brackets were selected from a virtual bracket library, and the case was submitted to DIBS AI for initial bracket positioning. This software-generated position served as a starting point and was the same for each participant. Participants were asked to adjust the software-generated bracket position to what they considered the ideal position. Participants were able to view a software-generated outcome simulation, which simulated alignment resulting from placement of a straight wire into the brackets. After bracket positioning was complete, the setup was saved and exported in STL format as *digital setup*.

The DIBS AI software allows the operator to move the teeth of segmented digital models individually. Using this feature, an ideal outcome model was created from the pretreatment model by an American Board of Orthodontics (ABO)-certified orthodontist using the ABO Cast-Radiograph Evaluation (CR-Eval) criteria as a guide. The CR-Eval is a model grading system used by the ABO to assess the quality of finished orthodontic cases. A CR-Eval score of 0 reflects an ideal outcome. After tooth positioning was complete, two ABO-certified orthodontists independently scored the ideal outcome model using CR-Eval criteria and confirmed a score of 0 in the categories that would be most affected by bracket positioning: alignment/rotations, marginal ridges, and occlusal contacts. Root angulation was not included in the scoring, as this could not be assessed from the simulation.

To create an ideal bracket setup, the DIBS AI software was then used to reverse-engineer the bracket positioning on the original pretreatment model that would result in the ideal outcome model. The resultant bracket setup was exported in STL format as *optimal setup* and used for comparison with the traditional and digital setups.

The setups of each participant were digitally superimposed using specialized software (Voyager Dental, Eden Prairie, Minn) as previously described.[11,12] To ensure that superimposition was based only on stable features, soft tissue and brackets were excluded from the surface used for superimposition. The models were initially registered through their approximation based on corresponding anatomy. An iterative closest-point matching algorithm was then used to achieve surface feature-based, best-fit superimposition.

Differences in bracket position were quantified as follows.[12] Four consistent datum points were placed at the surface of each bracket in the upper left, lower left, upper right, and lower right corners of the bracket base between the tie wings. For molar tubes, the datum points were placed at the junction of the bracket tube and the bracket base. An X-Y-Z coordinate system defining each bracket position in space was then automatically created based on these datum points (Figure 1). For each corresponding bracket pair in the superimposed setups, the software automatically computed the positional differences with respect to six dimensions of tooth movement: mesial-distal, buccal-lingual, and occlusal-gingival translation and torque,

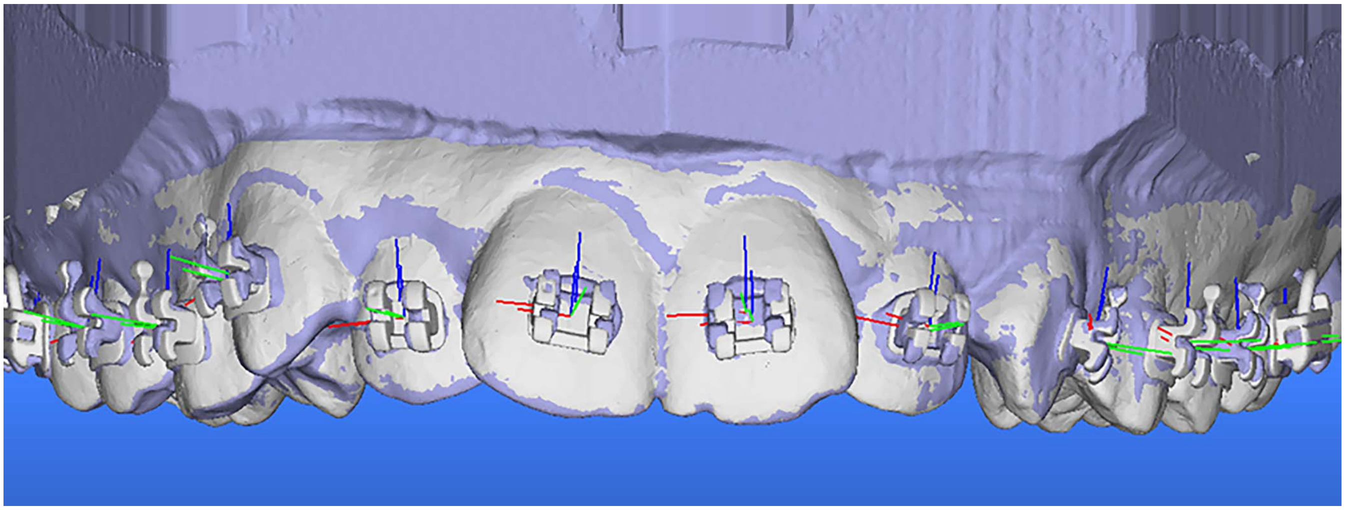

Figure 1. Superimposition of traditional (purple) and digital setups (gray). X-Y-Z coordinates (red, blue, green) represent bracket positions.

tip (angulation), and rotation. These differences described both the magnitude and direction of the discrepancy.[12] Importantly, only differences in mesial-distal translation, occlusal-gingival translation, and tip were considered in this study, as they would be most affected by bracket positioning.

The same process was repeated to superimpose the traditional and digital IDB setups of each participant onto the optimal setup to evaluate differences to the ideal bracket positions. The coordinate systems that were previously placed on both the traditional and digital setups were used for the bracket position difference computations. A total of 1800 bracket positioning differences were evaluated.

Statistical Analysis

To determine whether differences in bracket positions between traditional and digital, traditional and optimal, and digital and optimal setups were statistically significant, linear generalized estimating equation models were fit to account for repeated measurements in participants. The absolute values of the differences were used as the outcomes, and null hypotheses of 0.5 mm and 2° were tested with one-tailed tests. These limits were selected as clinically relevant because they represent accepted professional standards. The ABO deducts points for teeth that deviate 0.5 mm or more from proper alignment or alignment of marginal ridges.[13] A crown-tip positioning error of 2° causes a marginal ridge discrepancy of 0.5 mm in an average-sized molar. Models were adjusted by tooth type, arch type, mouth side, years of clinical experience, and whether IDB was used by the participants. Other variables were not included in the model due to high degrees of collinearity. To compare the differences between traditional and optimal and digital and optimal setups, the same approach was used, modeling the difference between the absolute values for the two separate comparisons (eg, digital vs optimal minus traditional vs optimal), and the null hypothesis value was set at 0 and used a two-tailed test. Significance levels were set a priori at 0.05. All analyses were performed in R version 4.3.1.

RESULTS

Participant characteristics are shown in Table 1. Participants had an average of 17.4 ± 14.0 years of clinical experience, and 8 (32%) routinely used IDB.

Differences in bracket positions between traditional and digital setups are shown in Table 2. The overall mean differences in bracket position were 0.28 mm for

Table 1. Participant Characteristics[a]

Characteristic	No. (%), n = 25
Years of clinical experience	
0–2	5 (20%)
3–10	5 (20%)
11–20	5 (20%)
21–30	4 (16%)
31+	6 (24%)
Comfort level with IDB	
Very uncomfortable	4 (16%)
Somewhat uncomfortable	4 (16%)
Neutral	1 (4.0%)
Somewhat comfortable	13 (52%)
Very comfortable	3 (12%)
No. of cases using traditional IDB	
<10	10 (40%)
10–20	2 (8.0%)
>20	13 (52%)
No. of cases using digital IDB	
<10	18 (72%)
10–20	2 (8.0%)
>20	5 (20%)

[a] IDB indicates indirect bonding.

Table 2. Traditional vs Digital Regression Results[a]

	Mesial-Distal	Occlusal-Gingival	Tip
Overall mean difference	0.28 (0.26, 0.31)	0.32 (0.28, 0.36)	3.4 (3.1, 3.8)*
Difference by tooth type			
Incisor	0.23 (0.21, 0.25)	0.33 (0.28, 0.37)	3.6 (3.1, 4.1)*
Canine	0.28 (0.25, 0.31)	0.35 (0.32, 0.38)	3.5 (3.0, 3.9)*
Premolar	0.32 (0.29, 0.36)	0.34 (0.27, 0.40)	3.8 (3.3, 4.4)*
Molar	0.34 (0.29, 0.39)	0.29 (0.18, 0.39)	2.1 (1.7, 2.5)
Difference by arch			
Maxillary	0.27 (0.25, 0.29)	0.35 (0.31, 0.40)	3.8 (3.4, 4.1)*
Mandibular	0.31 (0.28, 0.35)	0.29 (0.22, 0.37)	2.7 (2.5, 3.0)*

[a] Results are mean values (ranges).
* $P < .001$.

mesial-distal placement and 0.32 mm for occlusal-gingival placement. Differences in these linear measurements were significantly below the 0.5-mm limit. An overall mean difference of 3.4° was found for tip; this was significantly greater than the 2° limit. When adjusting for other variables, no significant differences larger than 0.5 mm were found in the mesial-distal and occlusal-gingival distances between traditional and digital setups for any tooth type. However, significant differences larger than 2° were found in tip for all tooth types except molars.

Differences in bracket positions between traditional and optimal setups are shown in Table 3. The overall mean difference was 0.25 mm for mesial-distal positioning, 0.32 mm for occlusal-gingival positioning, and 3.3° for tip. No statistically significant differences of more than 0.5 mm were found in the mesial-distal and occlusal-gingival measurements, but an overall difference of more than 2° was observed in mean bracket positioning for tip. When adjusting for other variables, again, no significant differences larger than 0.5 mm were found in the measurements between traditional and optimal bracket placement for any tooth type. However, significant differences larger than 2° were found in tip for all tooth types except molars.

Table 3. Traditional vs Optimal Regression Results[a]

	Mesial-Distal	Occlusal-Gingival	Tip
Overall mean difference	0.25 (0.24, 0.27)	0.32 (0.29, 0.34)	3.3 (3.1, 3.6)*
Difference by tooth type			
Incisor	0.20 (0.18, 0.23)	0.32 (0.27, 0.37)	2.9 (2.6, 3.3)*
Canine	0.23 (0.20, 0.25)	0.35 (0.29, 0.40)	3.8 (3.3, 4.2)*
Premolar	0.27 (0.25, 0.29)	0.31 (0.25, 0.36)	3.6 (3.2, 4.0)*
Molar	0.35 (0.30, 0.39)	0.29 (0.22, 0.37)	2.3 (1.9, 2.8)
Difference by arch			
Maxillary	0.28 (0.25, 0.31)	0.34 (0.30, 0.37)	3.5 (3.2, 3.7)*
Mandibular	0.24 (0.22, 0.26)	0.30 (0.25, 0.34)	2.9 (2.6, 3.1)*

[a] Results are mean values (ranges).
* $P < .001$.

Table 4. Digital vs Optimal Regression Results[a]

	Mesial-Distal	Occlusal-Gingival	Tip
Overall mean difference	0.26 (0.25, 0.28)	0.28 (0.25, 0.32)	2.9 (2.7, 3.0)*
Difference by tooth type			
Incisor	0.20 (0.18, 0.22)	0.39 (0.34, 0.44)	2.8 (2.6, 3.0)*
Canine	0.17 (0.14, 0.21)	0.24 (0.19, 0.29)	3.3 (3.0, 3.7)*
Premolar	0.37 (0.34, 0.40)	0.19 (0.15, 0.23)	3.4 (3.2, 3.6)*
Molar	0.26 (0.23, 0.28)	0.31 (0.27, 0.35)	1.4 (1.2, 1.7)
Difference by arch			
Maxillary	0.24 (0.22, 0.25)	0.29 (0.27, 0.31)	3.3 (3.2, 3.5)*
Mandibular	0.27 (0.25, 0.29)	0.27 (0.22, 0.33)	2.1 (2.0, 2.3)

[a] Results are mean values (ranges).
* $P < .001$.

Differences in bracket positions between digital and optimal setups are shown in Table 4. The overall mean difference was 0.26 mm for mesial-distal positioning, 0.28 mm for occlusal-gingival positioning, and 2.9° for tip. No statistically significant differences of more than 0.5 mm were found in the mesial-distal and occlusal-gingival measurements, but an overall difference of more than 2° was observed in mean bracket positioning for tip. When adjusting for other variables, again, no significant differences larger than 0.5 mm were found in the mesial-distal and occlusal-gingival distances between digital and optimal bracket positioning for any tooth type. However, significant differences larger than 2° were found in tip for all tooth types except molars.

Notably, none of the results were influenced by mouth side, years of clinical experience, and whether IDB was used by the participants.

Figure 2 is a visual representation of the difference in closeness to an optimal bracket position between the traditional and digital setups. Statistically significant differences were found between the overall closeness to the ideal position for tip but not for the mesial-distal or occlusal-gingival measurements. When adjusting for other variables, such as tooth type, arch type, or mouth side, significant differences were found in all measurements for some tooth types.

DISCUSSION

In this prospective in -vitro study, we assessed differences in bracket positioning between traditional and AI-assisted digital IDB methods and evaluated bracket positioning accuracy by comparing bracket positioning using these two methods, compared with an ideal model.

When assessing differences between the methods, the principal finding was that bracket positioning was similar using both traditional and digital methods, particularly in the linear dimensions. Differences in mesial-distal and occlusal-gingival bracket positioning were less than

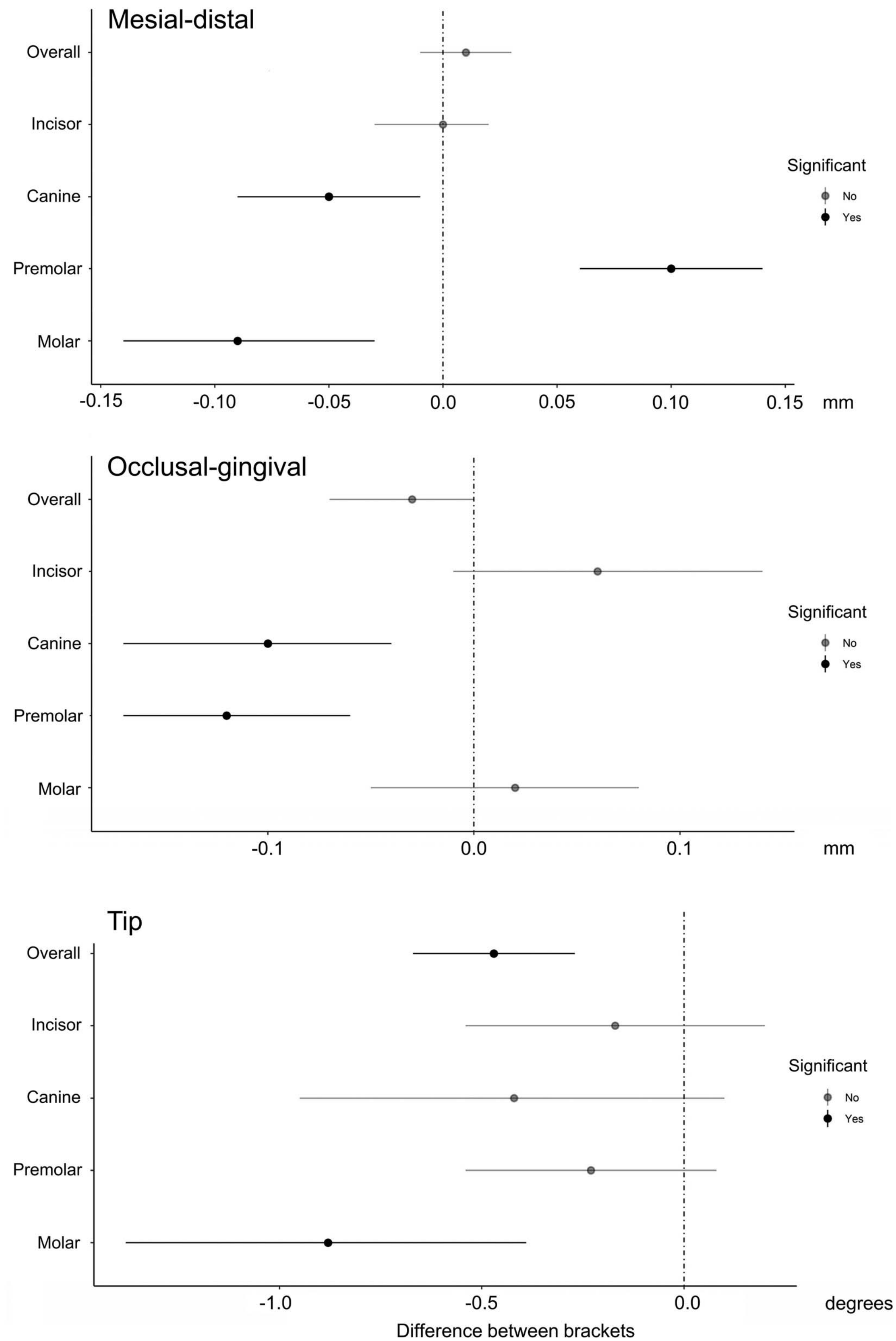

Figure 2. Digital vs optimal minus traditional vs optimal results. A negative effect indicates that the traditional method had a larger absolute difference from the optimal positioning than the digital method, while a positive effect indicates that the digital method had a larger absolute difference from the optimal positioning than the traditional method.

0.5 mm, suggesting that orthodontists tend to position brackets consistently in these dimensions, regardless of whether they use a physical or digital model. In contrast, differences in tip were significantly greater than 2° when comparing brackets placed via traditional and digital IDB. This suggested that the interface could have an influence on what orthodontists consider ideal bracket angulation.

When comparing accuracy of the methods, both the traditional and AI-assisted digital methods resulted in similar and highly accurate outcomes in the linear dimensions but not in tip. No significant differences were found from optimal bracket positions for the mesial-distal and occlusal-gingival dimensions; however, tip was significantly different from the optimal positions using both methods. While the bracket positions achieved with the digital method were generally closer to optimal positions, the differences were only significant for tip, with the digital method exhibiting slightly greater accuracy than the traditional method in this dimension. These findings suggest limited current usefulness of digital AI-assisted methods for optimizing orthodontic bracket positioning in linear dimensions, with greater utility for angulation.

Taken together, these findings suggest that bracket positioning is highly similar whether using a traditional or digital IDB method, with improved accuracy of bracket angulation with digital IDB. This supports the idea that clinicians who currently use traditional IDB methods may adopt AI-assisted digital IDB without compromising bracket positioning accuracy and may even gain improved accuracy in some dimensions.

Several researchers have found improved accuracy of bracket positioning when using traditional IDB[14,15] and digital IDB compared with direct bonding.[16,17] However, few researchers compared bracket positioning using traditional IDB and digital IDB. In 2011, Israel et al. compared bracket positioning using an early, semidigital IDB system to traditional IDB and found no significant differences in the overall ABO objective grading system score between the two.[18] More recently, Palone et al. found that cases treated with traditional and fully digital IDB systems had comparable outcomes, as indicated by similar reductions in the weighted Peer Assessment Rating values in vivo, with no significant differences between the groups.[19] These findings were consistent with those of the current study, in which we found limited differences in bracket position between traditional and digital IDB systems.

While digital IDB may currently offer only modest improvements in bracket positioning accuracy compared with traditional IDB, it provides several distinct advantages. These include the convenience of a fully digital workflow and computer-assisted bracket placement as well as reduction in human error and personnel costs in tray fabrication. Digital methods streamline the process by reducing the number of manufacturing stages and materials required.[4,5,20] Digital IDB is also more time-efficient, with virtual bracket positioning taking less time than manual positioning on models and the fabrication of digital transfer trays requiring less active working time.[21] Additionally, some evidence suggests that use of digital IDB results in more efficient treatment than traditional IDB, with fewer bracket repositioning appointments and shorter treatment duration.[19,22]

The use of AI is still a relatively new addition to the field of orthodontics and will likely see improvements with time.[23] It should be noted that all digital bracket setups in the current study, including the optimal setup, required modification from the initial computer-generated bracket position, suggesting that doctor review of AI-assisted bracket placement is necessary for achieving the best outcome.

A limitation of this study was that the same case was used for all participants. While this reduced variability, potential bracket positioning differences in different types of malocclusions could not be evaluated. Another limitation of the study was that the optimal bracket setup was created by using DIBS AI software to reverse-engineer a bracket setup which would result in an ideal outcome prediction. This relies on the assumption that the software outcome prediction is without error. Future in -vivo investigation is warranted to compare true outcomes using the two systems.

CONCLUSIONS

- Bracket positioning in linear dimensions is consistent and highly accurate with traditional and digital IDB methods.
- The AI-assisted digital IDB method provides usefulness for improving accuracy of bracket angulation.
- Clinicians who currently use traditional IDB methods may adopt AI-assisted digital IDB without compromising bracket positioning accuracy.

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DISCLOSURES

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