Original Article

Does clinical experience affect the bracket bonding accuracy of guided bonding devices in vitro?

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ABSTRACT

Objectives: To study whether and how the clinical experience of the operator affects the accuracy of bracket placement using guided bonding devices (GBDs) in vitro.

Materials and Methods: Five resin models were bonded virtually with brackets, and the corresponding GBDs were generated and three-dimensionally printed. Nine operators, which included three dental students, three orthodontic students, and three orthodontists, bonded the brackets on the resin models using GBDs on a dental mannequin. After being bonded with brackets, the models were scanned, and the actual and designed positions of the brackets were compared.

Results: There was no immediate debonding. The orthodontists spent a significantly shorter time (22.36 minutes) in bracket bonding than the dental students (24.62 minutes; $P < .05$). The brackets tended to deviate to the buccal side in the dental student group. Linear deviations tended to be smallest in the orthodontic student group, but no significant difference was found among operators with different clinical experience ($P > .5$). All linear and angular deviations in each group were under 0.5 mm and 2°, respectively.

Conclusions: Clinical experience was positively related to the bonding accuracy using GBDs, especially in the buccolingual dimension. Inexperience also led to longer bonding duration. However, bonding accuracy was clinically acceptable in general. (*Angle Orthod*. 2024;94:59–67.)

KEY WORDS: CAD/CAM; Clinical experience; Indirect bonding; Accuracy

INTRODUCTION

The prevalence of malocclusion is as high as 56% worldwide.[1] However, there is a shortage of orthodontists, especially those with experience. Accuracy in bracket bonding is important for successful orthodontic treatment with the straight-wire technique.[2] It relies much on treatment planning, observation, and operation[3,4] and, therefore, could be challenging for orthodontic students and orthodontic assistants. Specifically, unfamiliarity

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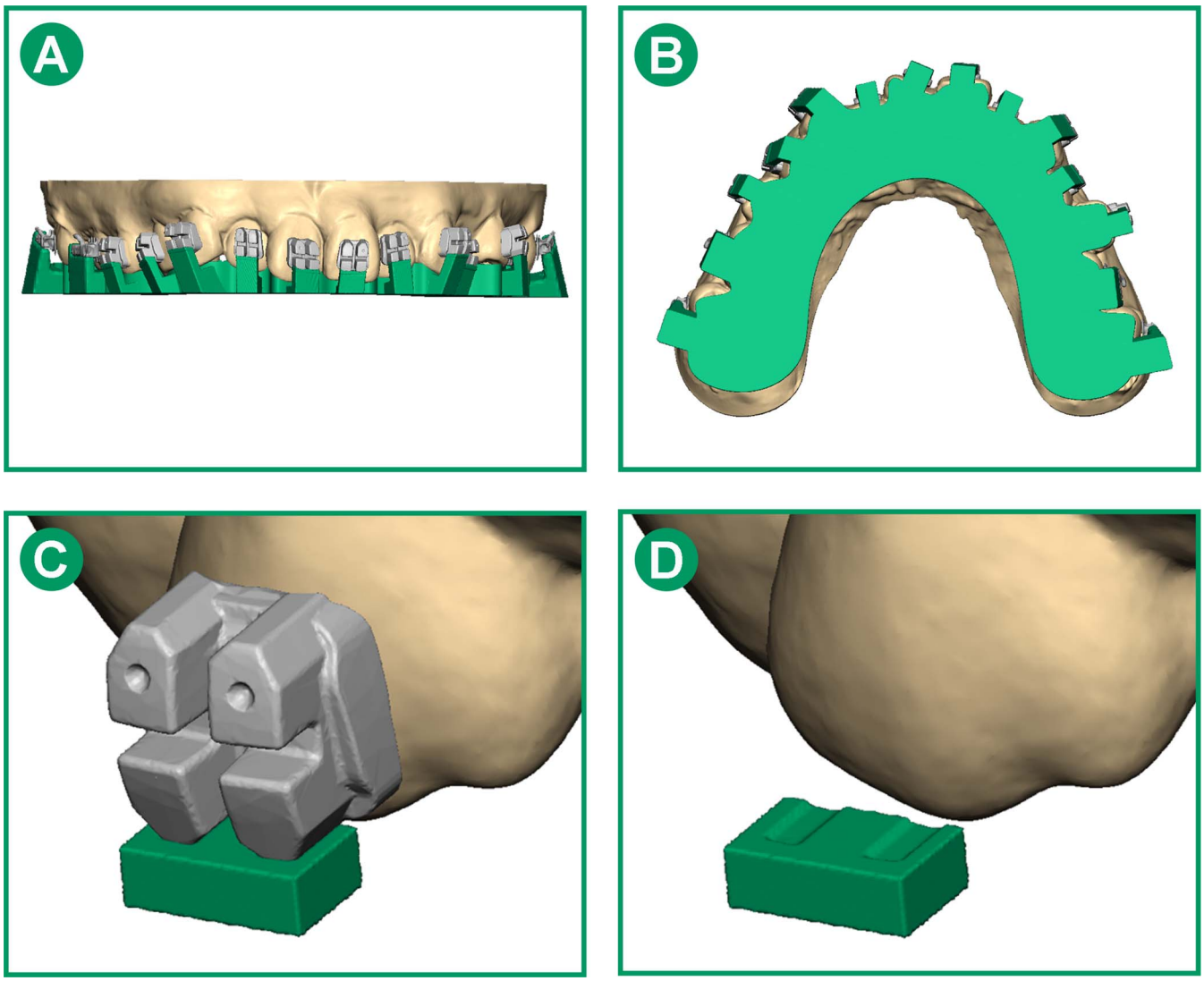

Figure 1. Design of the guided bonding device (GBD). (A) Frontal view and (B) occlusal view of the GBD. (C) Unilateral contact GBD guide block aligned to the mesial and distal sides of the bracket tie-wings and (D) special grooves that fit the occlusal side of the bracket tie-wings.

with the tooth morphology would lead to incorrect location of the facial axis (FA) points and inaccurate positioning of the brackets.[5] This may be aggravated under complicated conditions, such as crowded dentitions.[5,6]

With the aid of computer-aided design and computer-aided manufacturing (CAD/CAM) techniques, indirect bonding (IDB) devices have been improved in recent years.[7,8] The operators are able to observe the teeth on virtual models from different angles without obstruction and, therefore, it should be easier to determine the FA points for bracket placement. In addition, simulated alignment of the virtual dentition could also assist in the judgment of the bracket positions. Therefore, bracket bonding with CAD/CAM IDB devices could make bracket bonding more accurate and, therefore, have wide applicability.

However, because IDB devices cover the brackets, cases of bond failure with IDB devices are not rare,[9–11] and the applicability of IDB devices under complicated clinical scenarios is not yet clear. In 2020, a modified IDB device termed the guided bonding device (GBD) was proposed.[12] It is a CAD/CAM device with the advantages previously discussed. In addition, the bonding procedure with GBD is similar to that with direct bonding, making it more convenient to adjust and remove. Recently, the guides were futher modified with a horizontal surface to fit the occlusal side of the bracket tie-wings while the mesial/distal sides are aligned to the corresponding sides of the bracket (Figure 1).[13] The modified GBDs have been used in clinical orthodontic practice (Figure 2). However, it is not clear whether dentists or orthodontists with different levels of experience and expertise can achieve accurate bracket placement when using GBDs.

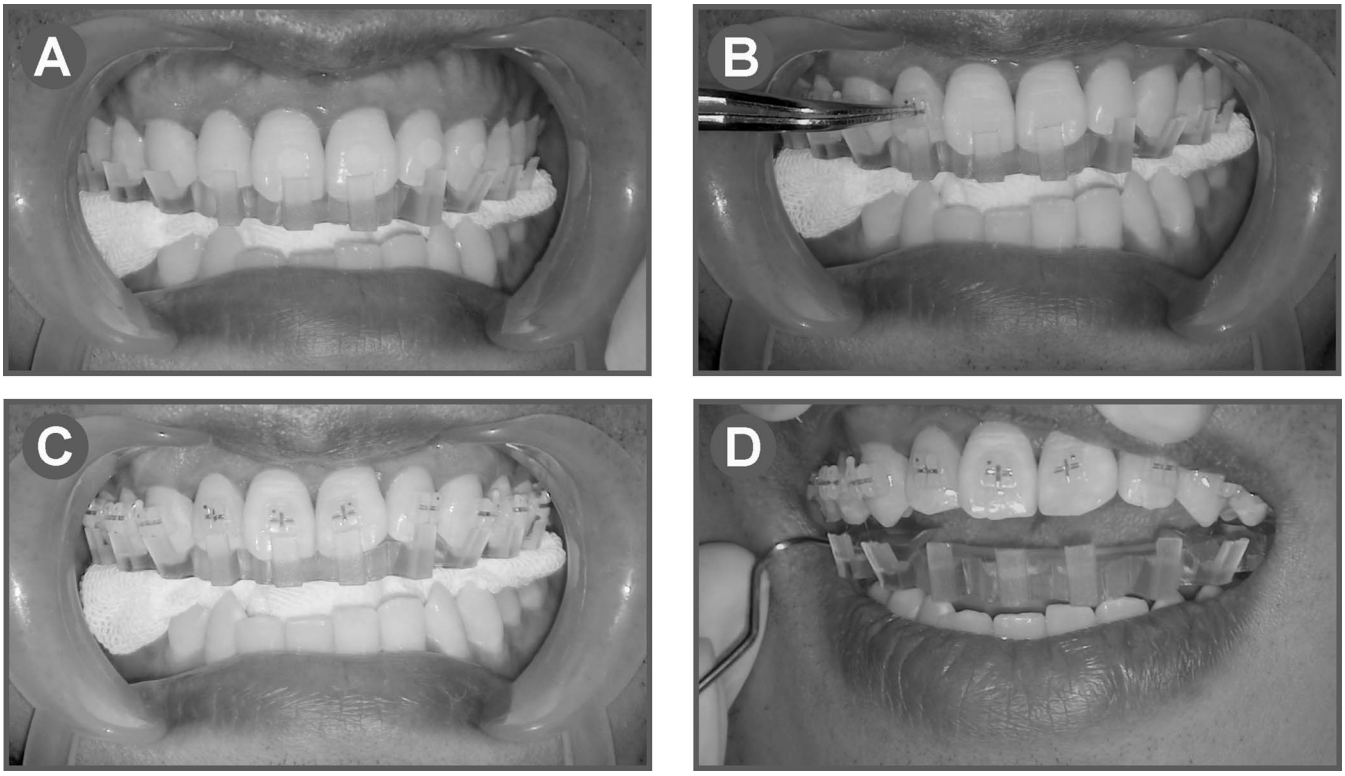

Figure 2. Use of the guided bonding device (GBD) in clinical practice. (A) Seating of the GBD. (B) Guided bracket bonding. (C) Bonded brackets. (D) Removal of the GBD.

Therefore, this study was designed to evaluate the accuracy of bracket placement with GBDs among operators with different levels of clinical experience. The study was conducted in vitro to reduce the effects of in vivo confounding factors, such as tooth size/shape variations, types of malocclusion, and patient cooperation, and concentrate specifically on the effect of operator clinical experience.

MATERIALS AND METHODS

The project was conducted after approval of the institutional ethical committee of West China Hospital of Stomatology, Sichuan University (WCHSIRB-D-2021-219). Informed consent was obtained from every bracket-bonding operator and patient whose dental model sets were enrolled. The workflow of this study is shown in Figure 3.

Inclusion of Nine Operators and Five Model Sets

Nine operators were enrolled in this study and were divided into three groups, each consisting of three operators: (1) dental students, (2) orthodontic students, and (3) orthodontists (Figure 4A). The dental students were inexperienced trainees who were new to dental clinical work, orthodontic students had less than three years of orthodontic working experience, and the orthodontists all had more than five years of working experience as orthodontic specialists (Supplemental Table S1).

Five dental model sets were enrolled. Inclusion criteria were the following: complete permanent dentition, clinical crown height adequate for accurate bracket placement, and dentition with moderate or severe crowding. According to the literature, moderate and severe crowding dentitions are those that require more than 4 mm of space for alignment.[14,15]

Virtual Bracket Bonding

The model sets were imported into OrthoAnalyzer 2015 (3Shape, Copenhagen, Denmark) for virtual bracket bonding with preadjusted edgewise brackets with 0.022-inch slots (Clarity, 3M Unitek, Monrovia, Calif) and buccal tubes (Shinye, Hangzhou, China). Virtual brackets were placed on FA point by an orthodontic expert and checked

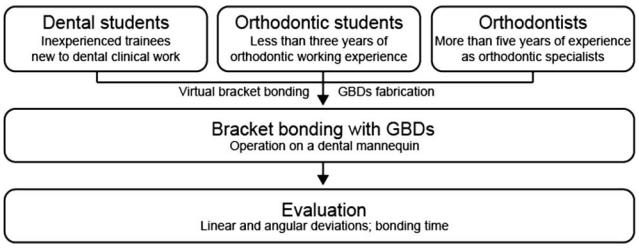

Figure 3. Flowchart of the present study. GBDs indicate guided bonding devices.

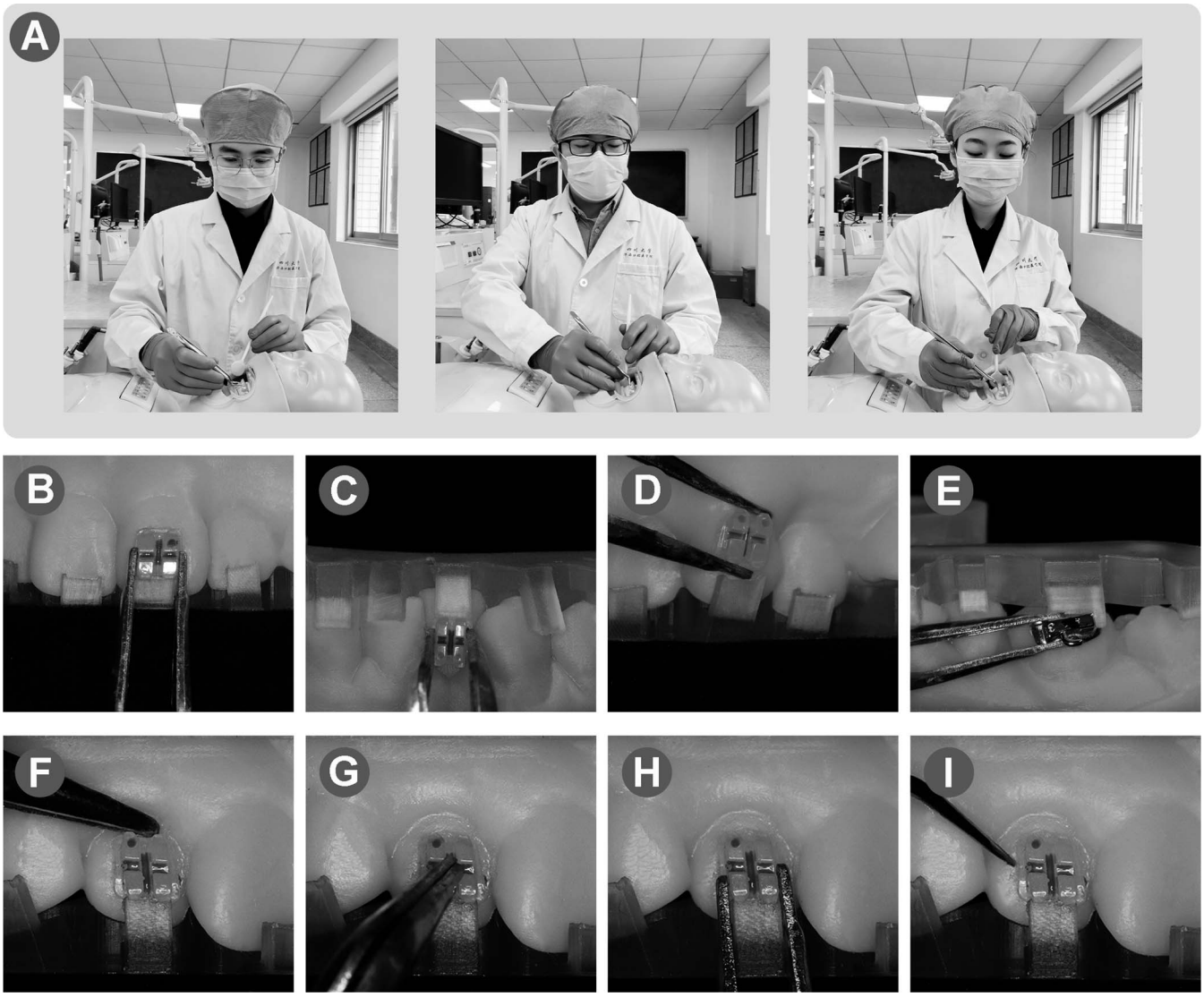

Figure 4. Guided bonding procedures. (A) One representative from each of the three groups of operators with different levels of clinical experience, that is, experienced orthodontists, orthodontic students, and dental students. (B, C) The brackets of the anterior teeth were held from the mesial and distal sides and (B) placed and moved along the teeth's long axes for the upper anterior teeth while (C) vertically placed on the labial surfaces for the lower anterior teeth. (D, E) The brackets of the posterior teeth were held from the occlusal and gingival sides and placed on the buccal surface. The brackets (F, G) were pressed against the guide block on the guided bonding device, and (H) the mesial and distal wings of the bracket were aligned to the corresponding edges of the guide block. (I) The excess adhesive was removed.

by three experts individually.[16] Then, models with brackets were imported into Geomagic Studio (version 2013; Geomagic, Morrisville, N.C.) and Freeform software (version 12.0; Geomagic) for GBD design, according to previous studies (Figure 1).[12,13]

The GBDs and the model sets were printed with a three-dimensional printer (NOVA3D, Nova Intelligent, Shenzhen, China).

In Vitro Bracket Bonding With GBDs by Different Operators

Preoperative Training. Three dental students, three orthodontic students, and three orthodontists were invited to bond the brackets. All operators underwent 1 hour of training to master the use of the GBDs. Training and bracket bonding were carried out in the National Demonstration Center for Experimental Teaching, West China School of Stomatology, Sichuan University.

Model Preparation and GBD Seating

The resin model sets were mounted on a dental mannequin and a cheek retractor was applied.

The GBDs were placed on the maxillary or the mandibular dental models. After the fit between the device and the dentition was checked, several cotton rolls were placed between the device and the opposing

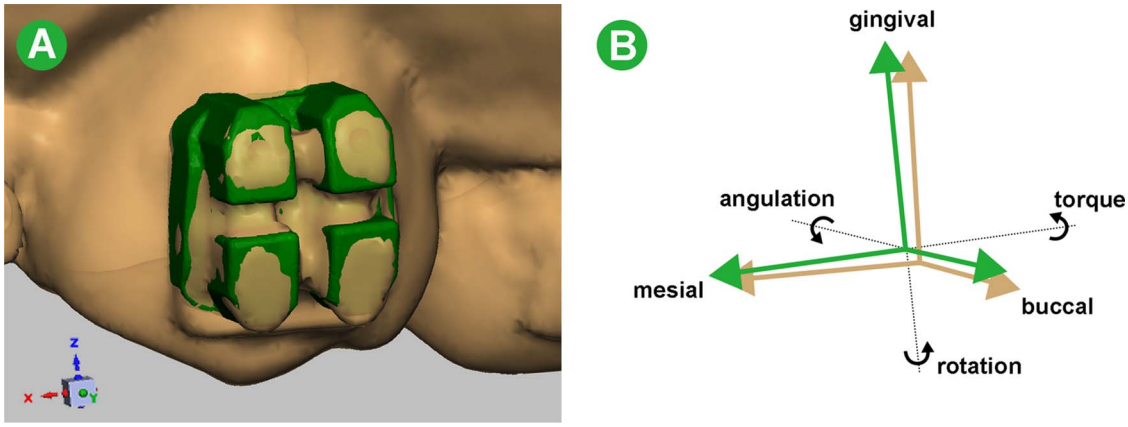

Figure 5. Measurement in six degrees of freedom. (A) The virtually bonded bracket (green) was superimposed on the scanned postbonded model (brown). (B) The deviations in six degrees of freedom were automatically calculated, as represented by the positional differences between the original local system representing the virtual bracket (green) and the local coordinate system representing the postbonded actual bracket (brown).

dental model. Finally, the mandible of the dental mannequin was fixed by tightening the simulated joint.

Bracket Bonding

Before bracket placement, primer (Transbond Moisture Insensitive Primer, 3M Unitek) was applied to the tooth buccal surfaces of the resin models. Then, brackets with adhesive (Transbond XT Light Cure Adhesive, 3M Unitek) were placed on the tooth surface and adjusted using a tweezer. Specifically, the brackets of the anterior teeth were held from the mesial and distal sides. For the upper anterior teeth, the brackets were placed and moved along the long axis (Figure 3B), whereas for the lower anterior teeth, the brackets were vertically placed on the labial surfaces (Figure 4C). The brackets of the posterior teeth were held from the occlusal and gingival sides and placed on the buccal surface (Figures 4D and 4E). The brackets were pressed against the guides of the GBDs, and the mesial and distal wings of the bracket were aligned to the corresponding edges of the guide block (Figures 4F–H). After adjustment, the brackets were pressed, and excess adhesive was removed (Figure 4I). After light-curing for 5 minutes, the devices were removed carefully. The operation time for the upper and lower dentition of each operator was recorded.

Evaluation of Bracket Bonding

The model bonded with brackets was scanned using a desktop scanner (DS 100+, Shining 3D, Hangzhou, China). The accuracy of bracket bonding was evaluated in Geomagic Studio according to the previous study using a local coordinate system.[12] In brief, a local coordinate system was created for every bracket and tube, and the origin was defined as the center point of the bracket groove. The mesiodistal, buccolingual, and vertical axes were set along the bracket slot, perpendicular to the lingual base of the bracket slot, and perpendicular to the other two axes. By selecting the same region on the virtual bracket and postbonded actual bracket, the virtual bracket with the local coordinate system was registered to the position of the postbonded actual bracket. Then, a new local coordinate system was generated in the position of the postbonded actual bracket correspondingly. The deviation of bracket bonding was defined as the positional difference between the virtual and actual bonded brackets/tubes, as represented by the differences between the two local coordinate systems. The linear (mesiodistal, vertical, buccolingual) and angular (torque, angulation, rotation) deviations were automatically calculated by comparing the position of the two local coordinate systems. Positive values were defined as a position more mesial, buccal, gingival, or with more buccal crown torque, more mesial angulation, or a buccal surface rotated more mesially than in the simulated position (Figure 5).

Statistical Analysis

The total sample size was 1260 (420 attachments per group bonded by three operators, three groups in all), and the power analysis for Kruskal-Wallis test (two-tailed) using G*Power (G*Power suite, 3.1.9.7, Düsseldorf, Germany) indicated 99.99% power to detect a small effect size (Cohen's $d = 0.25$) at a significance level of 0.05. Statistical analyses were performed using GraphPad Prism (version 8.0.1, GraphPad Software Inc., La Jolla, Calif).

Measurements were carried out on one randomly selected model set at a 2-week interval by the same investigator, and reproducibility of the measurements was evaluated using Bland-Altman plots. Descriptive analysis of the deviations was performed for all tooth types and different degrees of crowding, and absolute values of deviations were used for comparison.

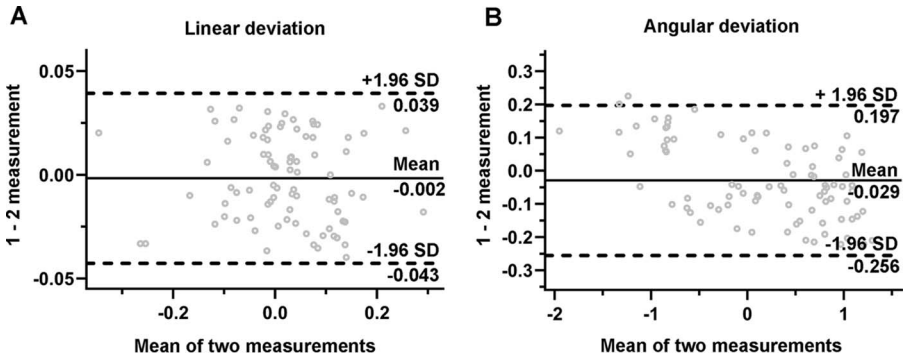

Figure 6. Reproducibility of measurement was evaluated using Bland-Altman plots for (A) linear and (B) angular deviations. SD indicates standard deviation.

According to previous studies,[12] the clinically acceptable limit was set at 0.5 mm for linear, and 2° for angular, deviations. The proportion of deviations below the limit in each group was calculated. Data normality was tested by Shapiro-Wilk test. Normally distributed data were analyzed with one-way analysis of variance, whereas the Kruskal-Wallis test (two-tailed) was used to compare the accuracy of the bonding among groups (significance level $\alpha = 0.05$) for the non-normally distributed data.

RESULTS

In total, 1260 attachments (900 brackets and 360 tubes) were bonded on 45 model sets. No immediate bonding failure was observed.

Reproducibility of the Measurement

The reproducibility of measurement was high as seen in the Bland-Altman plots (Figure 6). The difference for measurement of linear deviations ranged from −0.0443 mm to 0.0409 mm, with a mean ± standard deviation of −0.0017 mm ± 0.02 mm. The error for measuring angular deviations ranged from −0.2837° to 0.2201°, with a mean ± standard deviation of −0.0318° ± 0.13°.

Comparison of the Bonding Deviation Among Operators in Different Groups

For dental students, orthodontic students, and orthodontists, the mean linear deviations ranged from 0.083 mm to 0.094 mm, 0.062 mm to 0.074 mm, and 0.072 mm to 0.087 mm, respectively, whereas the angular deviations ranged from 0.803° to 0.884°, 0.809° to 0.842°, and 0.787° to 0.842°, respectively (Table 1). No significant difference was found in linear and angular deviations among the three groups or among the three operators within the same groups.

Directional Tendency of the Bonding Deviations

Regarding the directions of the bonding deviations, the brackets tended to be buccally and gingivally positioned in all groups (Table 2). Of the brackets bonded by the dental students, 71.19% deviated buccally, whereas only 56.43% and 59.29% of the brackets showed the same tendency for orthodontic students and orthodontists, respectively. For vertical deviations, 62.62%, 66.19%, and 58.81% of the brackets deviated to the gingival side in the dental students, orthodontic students, and orthodontists, respectively. No directional tendency was observed in the mesiodistal dimension and the three angular dimensions (Table 2). The deviation among operators within the groups was not statistically different ($P > .05$).

Duration for Bracket Bonding

The duration for bracket bonding referred to the time required from the placement of the brackets to light-curing, excluding the time for the GBD seating and removal. With the increase in clinical experience,

Table 1. Linear and Angular Deviations in Different Groups

		Median ± Quartile					
		Linear Deviations (mm)			Angular Deviations (°)		
Group	n	Mesiodistal	Buccolingual	Vertical	Torque	Angulation	Rotation
Dental students	420	0.084 ± 0.11	0.083 ± 0.10	0.094 ± 0.13	0.803 ± 0.45	0.884 ± 0.52	0.816 ± 0.59
Orthodontic students	420	0.065 ± 0.10	0.062 ± 0.10	0.074 ± 0.12	0.809 ± 0.65	0.842 ± 0.54	0.826 ± 0.62
Orthodontists	420	0.073 ± 0.11	0.072 ± 0.11	0.087 ± 0.13	0.787 ± 0.60	0.842 ± 0.47	0.819 ± 0.55

Table 2. Directional Prevalence of the Bonding Deviations in Different Groups[a]

		Linear Deviation						Angular Deviation					
		Mesiodistal		Buccolingual		Vertical		Torque		Angulation		Rotation	
Group	n	Mesial (%)	Distal (%)	Lingual (%)	Buccal (%)	Gingival (%)	Occlusal (%)	LCT (%)	BCT (%)	MRT (%)	DRT (%)	M-L (%)	M-B (%)
Dental students	420	59.5	40.5	28.8	71.2	62.6	37.4	41.9	58.1	51.4	48.6	50.7	49.3
Orthodontic students	420	46.9	53.1	43.6	56.4	66.2	33.8	49.5	50.5	50.2	49.8	52.4	47.6
Orthodontists	420	54.5	45.5	40.7	59.3	58.8	41.2	49.1	51.0	51.2	48.8	51.2	48.8

[a] BCT indicates buccal crown torque; DRT, distal root tip; LCT, lingual crown torque; M-B, mesiobuccal; M-L, mesio-lingual; and MRT, mesial root tip.

the operators spent less time in bracket bonding, with a statistically significant difference between the orthodontists (22.36 minutes) and the dental students (24.62 minutes) (Table 3). Overall, the bracket bonding time for the upper dentition was longer than that for the lower dentition, although no statistically significant difference was found between them (Table 3).

Clinical Acceptability of the Bracket Bonding

Nearly all the bracket bonding deviations fell under the clinically acceptable limit (0.5 mm for the linear deviations and 2° for the angular deviations). That is, 97.3%, 97.2%, and 98.7% linear bonding deviations, and 96.9%, 97.6%, and 98.5% angular deviations of brackets bonded by dental students, orthodontic students, and orthodontists, respectively, were clinically acceptable (Table 4).

DISCUSSION

This study investigated the accuracy of bracket bonding using GBDs by operators with different levels of clinical experience. In general, bonding accuracy was acceptable for the dental students, orthodontic students, and orthodontists, and no statistically significant difference was found in bonding deviations among the three groups of operators.

CAD/CAM GBDs

Accurate bracket bonding relies on accurate observation, precise operation, and appropriate treatment planning.[3,4] However, these skills require practice and are hard to master for orthodontic students or orthodontic assistants. The CAD/CAM IDBs developed in recent years may be a good solution.[12,17,18] The digital model generated used in the CAD process made it possible for the operators to observe the tooth morphology from multiple views, thus aiding the precise location of the FA point.[5] Also, the virtual alignment feature makes it easier to evaluate the treatment plan, further facilitating the determination of the bracket position.

As a modified version of CAD/CAM IDB device, GBD[12] also has the same advantages. GBDs were first proposed by Xue et al.[12], featuring a CAD/CAM bilateral contact GBD (GBD-B) with L-shaped guides with vertical and horizontal arms that ensured the mesiodistal and vertical positions of the bracket, respectively. However, the vertical arm may impede the positioning of tweezers and visual access to the posterior teeth. Wang et al.[13] solved the problem by simplifying the guide into blocks with special grooves (unilateral contact GBD [GBD-U]), only contacting the occlusal side of the brackets. Their results indicated that the GBD-U had higher bonding accuracy in the mesiodistal dimension, torque, angulation, and rotation than the GBD-B. Therefore, the present study used the modified version of GBD (GBD-U) with guide blocks (Figure 1).[12] The bonding procedure was similar to that of direct bonding, and the operation was therefore easy to learn, especially for the starters.

Table 3. The Duration (Minutes) for Bracket Bonding in Different Groups[a]

	Mandible	Maxilla	Total
Dental students	12.7 ± 1.6	11.9 ± 1.3*	24.6 ± 2.2*
Orthodontic students	11.8 ± 0.5	11.4 ± 0.8	23.2 ± 1.0
Orthodontists	11.6 ± 1.5	10.7 ± 0.9*	22.4 ± 2.4*

[a] The duration was given as mean ± standard deviation.
* $P < .05$.

GBDs Achieved Accurate Bracket Bonding for Both Experienced and Inexperienced Operators

The results showed that the three groups of operators were able to position the brackets accurately, with nearly all brackets with bonding deviations within the clinically acceptable limit. Although the bonding deviations of dental students were greater than those of the other two groups, there was no significant difference among the three groups,

Table 4. Clinical Acceptable Prevalence of the Bonded Brackets

	Linear Deviations (%)				Angular Deviations (%)				
Group	Mesiodistal	Buccolingual	Vertical	Total	Torque	Angulation	Rotation	Total	Total (%)
Dental students	96.9	96.7	98.3	97.3	97.1	96.0	96.7	96.6	96.9
Orthodontic students	97.1	96.9	97.6	97.2	98.3	97.4	98.3	98.0	97.6
Orthodontists	97.6	98.8	99.5	98.7	98.1	98.6	98.1	98.3	98.5

indicating that GBDs enable accurate bracket placement for operators with different dental and orthodontic experiences.

Orthodontic Experience Improved the Bonding Efficiency Using GBDs

As the level of clinical experience increased, the time spent on bracket bonding was reduced, similar to a study on direct bonding where it took more time for the dental students to place the brackets.[6] Presumably, although dental students had been trained beforehand, they were still unskilled in operation and unfamiliar with the use of tweezers or other dental instruments. Interestingly, brackets bonded by the dental students showed a higher tendency for buccal displacement, probably as a result o insufficient compression during bonding. Therefore, it is indispensable to establish a detailed and precise workflow.

Limitations and Future Studies

The results supported that GBDs can help the accurate bracket position by operators with different levels of experience. A more detailed workflow needs to be proposed for inexperienced operators to master GBDs more quickly. Future in vivo use of GBDs by orthodontic students or orthodontic assistants should also be validated.

CONCLUSIONS

- Clinical experience had little influence on the accuracy of bracket placement with GBDs.
- More experienced clinicians performed the bonding procedure more efficiently.

ACKNOWLEDGMENTS

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SUPPLEMENTAL DATA

Supplemental Table 1 is available online.

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