AJO-DO

Accurate bracket placement using a computer-aided design and computer-aided manufacturing–guided bonding device: An in vivo study

Chaoran Xue,[a] Hui Xu,[a] Yongwen Guo,[a] Li Xu,[b] Yogyata Dhami,[a] Hongzhe Wang,[a] Zhongyu Liu,[a] Jianbin Ma,[a] and Ding Bai[a]
Chengdu and Hangzhou, China

Introduction: A protocol was introduced to achieve accurate bracket placement in vivo, which consisted of operative procedures for precise control, and a computer-aided design and computer-aided manufacturing–guided bonding device. To evaluate the accuracy of this protocol, a 3-dimensional assessment was performed. **Methods:** Ten consecutive patients were enrolled. Strictly following the protocol, from December 2017 to March 2018, brackets were placed on the teeth of each patient using the device. To evaluate the accuracy, deviations of positions and orientations for bracket placement were measured. Each patient was followed up after 3 months regarding bracket failures. **Results:** The guided bonding device was used in all cases, and a total of 205 brackets were successfully bonded and evaluated. Except for 15.12% brackets with torque deviation over 2°, the deviations in mesiodistal, buccolingual, vertical, rotation, and angulation were below the clinical acceptable range (0.5 mm in translation or 2° in orientation) for all brackets. In the 3-month follow-up, there was no bracket failure in any patient. **Conclusion:** This protocol transferred the planned bracket position from the digital setup to patient's dentition with generally high positional accuracy. (Am J Orthod Dentofacial Orthop 2020;157:269-77)

Effective and efficient orthodontic treatment is based on the concept that ideal bracket placement will correct tooth positions in all 3 spatial planes. Orthodontists have striven to improve the accuracy of the bracket bonding for years.[1] Since the introduction, in 1972, by Silverman et al,[2] of transfer trays of indirect bonding, technique has improved with regard to design and fabrication; for example, polyvinyl siloxane trays,[3-5] vacuum-formed trays,[5-7] combination of polyvinyl siloxane and vacuum-formed trays,[8] 3-dimensional (3D) printed trays,[9-11] and transfer jigs.[12] Among these approaches, there are 3 major common steps in the fabrication of a traditional transfer tray: bonding brackets on a stone model, forming the transfer tray, and then removing the transfer tray with brackets from the stone model.[2-4,6-8] In this lengthy process, much experience and skillful operation are required by the technician to reduce errors in each step of the process. The high sensitivity of the technique makes it difficult to popularize in clinical practice.

Intraoperatively, there are 2 critical steps needed to succeed in indirect bonding. First, seat the transfer tray completely on the patient's dentition. Second, assess and control the bracket position intraoperatively. However, the elastic property of most transfer trays makes it difficult to differentiate among incomplete seating, complete seating, and over seating of the transfer tray for each single tooth when individualized finger pressure is applied.[13] Moreover, because the brackets are partially or completely covered by the transfer tray, there is a lack of visibility, making it difficult to tell whether the bracket is in the predetermined position, as well as limiting access to adjust the bracket position or remove the excess adhesive immediately.[9-11] Thus, transferring the bracket position to the patient's dentition with accuracy is

[a]Department of Orthodontics and Paediatrics, State Key Laboratory of Oral Diseases, National Clinical Research Center for Oral Diseases, West China Hospital of Stomatology, Sichuan University, Chengdu, Sichuan, China.
[b]Department of Orthodontics, Affiliated Hospital of Stomatology, Medical College, Zhejiang University, Hangzhou, Zhejiang, China.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Address correspondence to: Ding Bai, Department of Orthodontics and Paediatrics, State Key Laboratory of Oral Diseases and National Clinical Research Center for Oral Diseases and Department of Orthodontics and Paediatrics, West China Hospital of Stomatology, Sichuan University, Chengdu, Sichuan, China; e-mail, baiding@scu.edu.cn.
Submitted, October 2018; revised and accepted, March 2019.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2019.03.022

challenging for orthodontists with limited experience, especially on dentitions with various malocclusion and intraoral complications. To overcome the above drawbacks, development of a simple and efficient way of indirect bonding with accuracy is warranted, and precise intraoperative control is equally important to achieve accurate bracket placement based on a well-fabricated tray.

In this prospective study, a protocol was introduced to achieve accurate bracket placement. This protocol consisted of operative procedures for precise control, and a computer-aided design and computer-aided manufacturing–guided bonding device. In addition, a 3D assessment was performed to evaluate the accuracy of bracket placement.

MATERIAL AND METHODS

Ten consecutive orthodontic patients (6 women and 4 men) were enrolled. All subjects had permanent dentitions and full clinical crown heights were available. Subjects with the following indications were excluded: (1) teeth that were not planned for bracket bonding at the start of treatment, (2) teeth with defects that could affect bracket placement, and (3) teeth with inadequate space that limited bracket placement owing to the initial malocclusion. The bracket placement was performed in each patient by the same orthodontist using the guided bonding device from December 2017 to March 2018 in West China Hospital of Stomatology, Sichuan University, Chengdu, China. The Helsinki Declaration was followed during the performance of this study. The project was under the approval of the local institutional ethical committee and every participant signed an informed consent form.

Digitized dentition of each patient was acquired using an intraoral scanner (3Shape TRIOS, Copenhagen, Denmark). Using a 3Shape OrthoAnalyzer 2015, preadjusted edgewise brackets with 0.022-inch slot (Clarity Adhesive Coated Advanced Brackets, 3M Unitek, Monrovia, Calif) were virtually bonded on incisors, canines, and premolars, and buccal tubes (Shinye Orthodontic Products, Hangzhou, China) were placed on the first molars. Then, the digitized models with brackets, also termed simulative dentitions, were exported in stereolithography format.

Using the simulated dentitions, the guided bonding device was designed in Freeform software (version 12.0; Geomagic, Morrisville, NC). It consisted of 3 parts: (1) an L-shaped guides that fit the occlusal and distal edge of the tie-wings on the bracket, (2) a splint that covers the occlusal surface completely or partially, and (3) connecting rods that join the other 2 parts (Fig 1). The device was then fabricated using a 3D printer.

Precise control of bracket placement

Fitness between the device and the stone model: The guided bonding device was placed on the stone model. Position deviation and fitness were compared from the buccal and lingual sides against the virtual design on the computer. If any deviation, misfit, or space was detected, the orthodontist would grind the region in contact with deep grooves or walls between neighboring teeth. If the misfit was still detected, the orthodontist would forgo the guiding device and refer to traditional direct bonding (Fig 2).

Fitness between the device and the dentition: After the dentitions were isolated using a plastic mouth opener with a cheek retractor, the teeth surfaces were cleaned with 95% alcohol. The buccal surfaces were then etched with 37% phosphoric acid (Eco-Etch, Ivoclar Vivadent, Schaan, Liechtenstein) for 20 seconds, rinsed with water for 30 seconds to ensure complete removal of the etchant, and air-dried until they appeared dull and frosty.

Subesequently, the sterilized-guided bonding device was seated over the upper dentition. Position deviation and fitness were visually checked again. If no deviation, misfit, or space was detected, the orthodontist would put gauze balls in the lingual and occlusal sides of the device. Then, the patient would be asked to bite through the gauze balls to fix the device on the dentition. If not, the orthodontist would forgo the guiding device and refer to traditional direct bonding.

Control of bracket placement in 3 directions: After the primer (Transbond Moisture Insensitive Primer, 3M Unitek, Monrovia, Calif) was applied to the teeth using a brush, the bracket with adhesive was placed on the tooth surface using the forceps by pressing as with direct bonding, and excessive adhesive around the bracket was removed. This process ensures the buccolingual position of the bracket. The position of the bracket was then adjusted to fit the L-shaped guide, ensuring the mesiodistal and vertical positions of the bracket. After all brackets were correctly placed, the light-curing lamp was used on each tooth.

Removal of the device: The gauze balls were removed first. As the undercut was eliminated because (1) the splint only had contact with the occlusal surface of the dentition, (2) the L-shaped guides only had contact with the distal and occlusal sides of the bracket, and (3) a certain distance existed between the L-shaped guides and the tooth surface, the device could be directly pried away from the dentition with a probe.

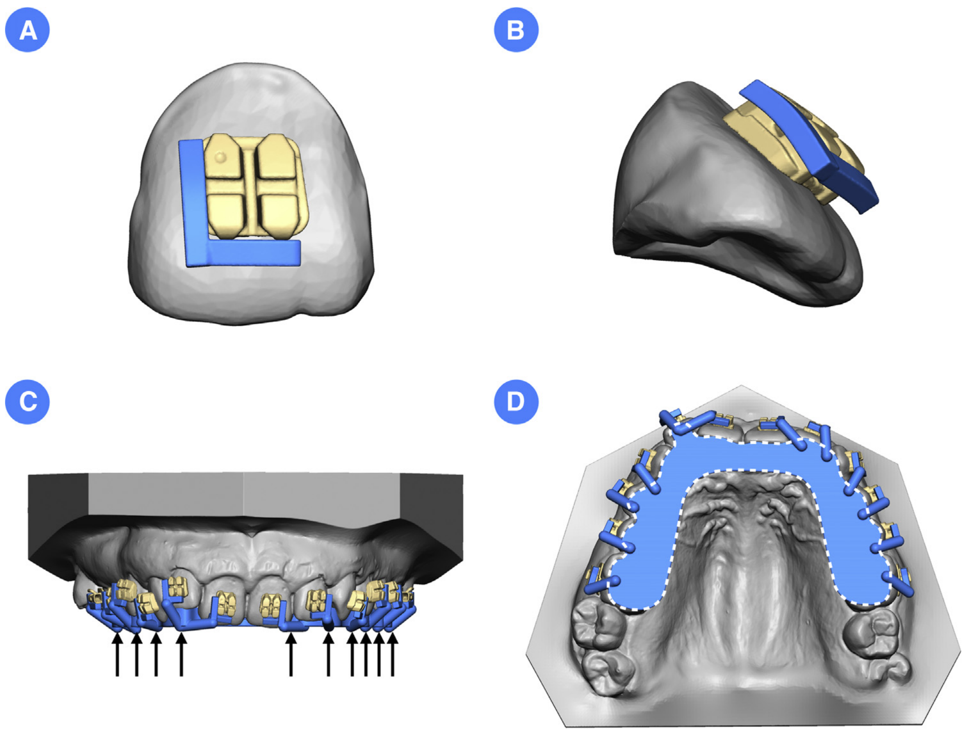

Fig 1. The design of the guided bonding device. **A**. The 2 arms of the L-shaped guides were just against the occlusal and distal edge of the bracket. **B**. It is suspended a certain distance from the buccal-labial surface. **C**. Front view of the device, in which the black arrows show the connecting rods. **D**. Occlusal view of the device, in which the splint is surrounded by a dotted line.

For the lower dentition, the same operation (steps 2 to 4) was performed. Each patient was followed up after 3 months with regard to failure of the brackets.

Assessment of accuracy for bracket placement

After bracket bonding, the dentitions with brackets, termed postoperative dentitions, were dried and made antireflective using a scanning preparation spray (Cerec Optispray, Sirona Dental Systems). Then, they were scanned and digitized using an intraoral scanner (3Shape TRIOS). By selecting the same region (teeth, except for the buccal surface with brackets), each tooth on the simulative dentitions was registered to the postoperative dentitions in Geomagic Studio 2013 (version 2013; Geomagic, Morrisville, NC).

Each bracket of the simulative dentitions was constructed with a local coordinate system, termed a simulative bracket (Fig 3, *A*). By selecting the same region on the simulative bracket and postoperative bracket, the simulative bracket with the local coordinate system was registered to the position of postoperative bracket. Then, the postoperative bracket was represented by the duplication of the simulative bracket (colored in red) with a local coordinate system (colored in yellow) in the position of the postoperative bracket. By comparing the position of the 2 local coordinate systems (colored in blue and yellow), the position deviations in mesiodistal, buccolingual, and vertical orientations, and the orientation deviations in torque, angulation, and rotation were automatically computed.

Statistic analysis

Statistical analyses were performed using SPSS 16.0 (SPSS Inc, Chicago, Ill) and MedCalc 15.0 (MedCalc Software, Mariakerke, Belgium). To evaluate the reproducibility of measuring deviations of positions (mesiodistal, vertical, and buccolingual) and deviations of orientations (torque, angulation, and rotation), 20 brackets were randomly selected. And the measurements for each bracket were performed by the same investigator after an interval of 2 weeks. Bland-Altman plots were used to assess the quality of reproducibility.

For the assessment of accuracy for bracket placement, mean position deviations (mesiodistal, buccolingual, and vertical) (n = 615, 205 brackets), and mean

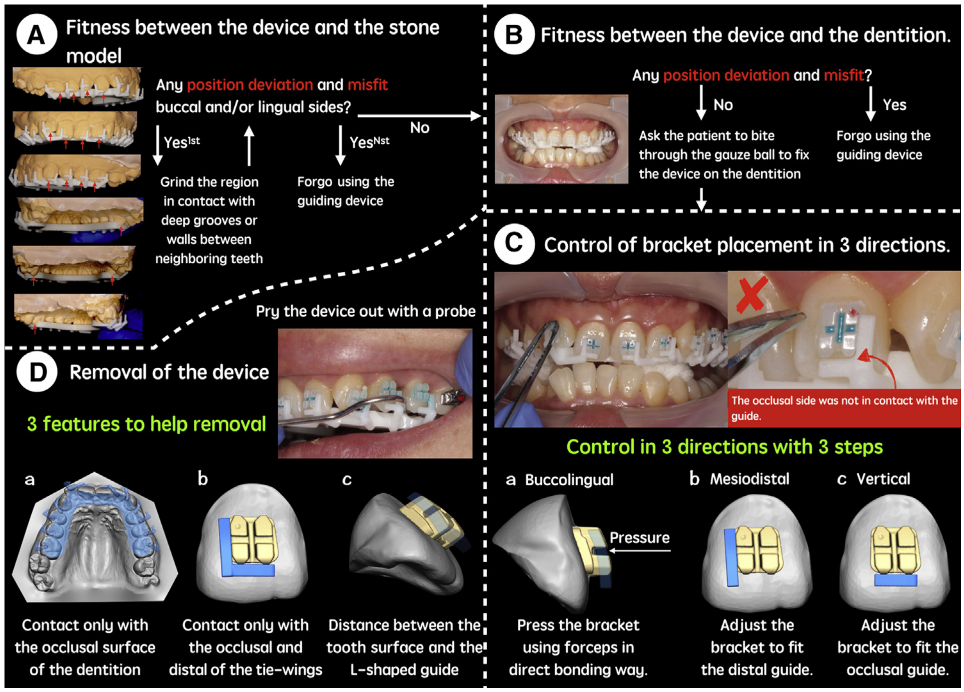

Fig 2. Precise control for accurate bracket placement. **A**. Check of suitability of the device and the stone model using buccal and lingual views. **B**. Check of fitness between the device and the dentition. **C**. Control bracket placement in 3 directions: (a) the buccolingual position was controlled by pressing the bracket using the forceps in a direct bonding manner; (b) the mesiodistal position was controlled by adjusting the bracket to fit the distal guide; (c) the vertical position was controlled by adjusting the bracket to fit the occlusal guide. **D**. Removal of the device. The device was easily pried away from the dentition with a probe using 3 features: (a) the splint was only in contact with the occlusal surface of the dentition, (b) the L-shaped guides were only in contact with the distal and occlusal sides of the bracket, and (c) a certain distance was maintained between the L-shaped guides and the tooth surface.

orientation deviations (torque, angulation, and rotation) of brackets between the simulative and postoperative groups are presented (n = 615, 205 brackets). Shapiro-Wilk test showed that the variables were not normally distributed. To compare the deviations above with a clinical acceptable error (0.5 mm in translation or 2° in orientation),[14] Wilcoxon matched-pairs signed rank test was applied for non-normally distributed variables. A level of á = 0.05 was set for significance.

In addition, the directionality and frequency of error resulting from the bracket transfer during guided bonding were calculated for each tooth type (incisors, canines, premolars, and molars) and the complete dataset.

The sample size was determined according to previous studies.[5,15] With an observed sample size of n = 205, a power analysis for Wilcoxon matched-pairs signed rank test (2-tailed) conducted a posteriori using G*Power 3.1.9.3 indicated 100% power to detect a small effect size (Cohen's d = 0.4) at a significance level of 0.05.

RESULTS

In total, 205 brackets (from 18 dentitions, 10 patients) were bonded using the device. Before bonding, misfit was found in the region of crowded anterior teeth in 2 cases. After grinding the walls between neighboring teeth, all devices fit the stone model well. Intraoperatively, no misfit was found regarding the placement of the guided bonding device on the dentitions. All bracket placements were guided by the L-shaped guides. No difficulty was found in removal of the device in any case.

The guided bonding device provided accurate bracket placement. The reproducibility of the measurement was verified. The error of measuring position deviation ranged from −0.010 to 0.010 mm, with a mean (standard deviation [SD]) of −0.001 (0.004) mm. The error of measuring orientation deviation ranged from −0.30° to 0.28°, with a mean (SD) of −0.012° (0.109°). In the Bland-Altman plots, most values ranged within a mean of ± 1.96 (SD), which confirmed the

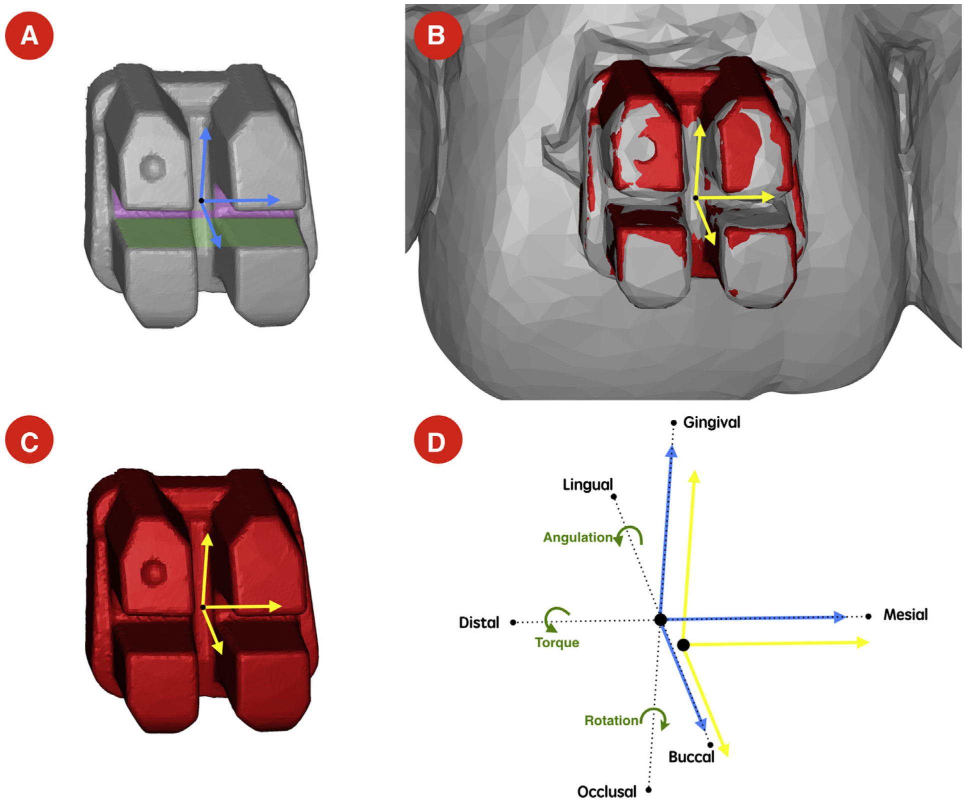

Fig 3. Assessment of accuracy in 6 directions using a semiautomated method. **A**. The local coordinate system (*blue*) was established on the bracket of simulative dentition (simulative bracket). The origin is set on the center point of the bracket base. The mesiodistal axis is set along the bracket slot. The buccolingual axis is set perpendicular to the lingual base of the bracket slot (*purple*). The vertical axis is set perpendicular to the occlusal base of the bracket slot (*green*). **B**. By selecting the same region on the simulative bracket and postoperative bracket, the simulative bracket with local coordinate system was registered to the position of the postoperative bracket. **C**. The postoperative bracket is represented by the duplication of the simulative bracket (*red*) with the local coordinate system (*yellow*) in the position of postoperative bracket. **D**. By comparing the position of the 2 local coordinate systems (*blue and yellow*), the mesiodistal, buccolingual, and vertical position deviations and the orientation deviations in torque, rotation, and angulation were automatically computed.

reproducibility of measuring position deviations and orientation deviations (Fig 4).

The position and orientation deviations between simulative and postoperative groups were presented in Table I. The position deviations of brackets in the in mesiodistal, vertical, and buccolingual orientations were much less than 0.5 mm for all brackets, with a mean value (SD) of 0.009 (0.091) mm (P <0.001), 0.060 (0.131) mm (P <0.001), and −0.087 (0.047) mm (P <0.001), respectively. The orientation deviations in torque, angulation, and rotation of bracket were much less than 2° for all brackets, with a mean value of 0.286° (1.276°) (P <0.001), 0.061° (0.806°) (P <0.001), and −0.015° (0.903°) (P <0.001), respectively.

For the frequencies of error resulting from the bracket transfer for each tooth type, the transfer accuracy was lowest for torque (84.88% brackets with error no more than 2° in torque), as all the brackets were within a clinically acceptable range (0.5 mm in translation or 2° in orientation) in the other 5 directions. The frequencies of directional bias resulting from the guided bonding method are shown in Table II.

No bonding failure was found in any patient in the 3-month follow-up.

DISCUSSION

Ideal bracket placement starts with a thorough and systematic diagnosis. Accurate transfer of ideal bracket placement is invaluable not only for orthodontic treatment with the traditional straight-wire appliance, but for the latest computer-assisted orthodontic treatment with customized brackets and robot-bent wires. In

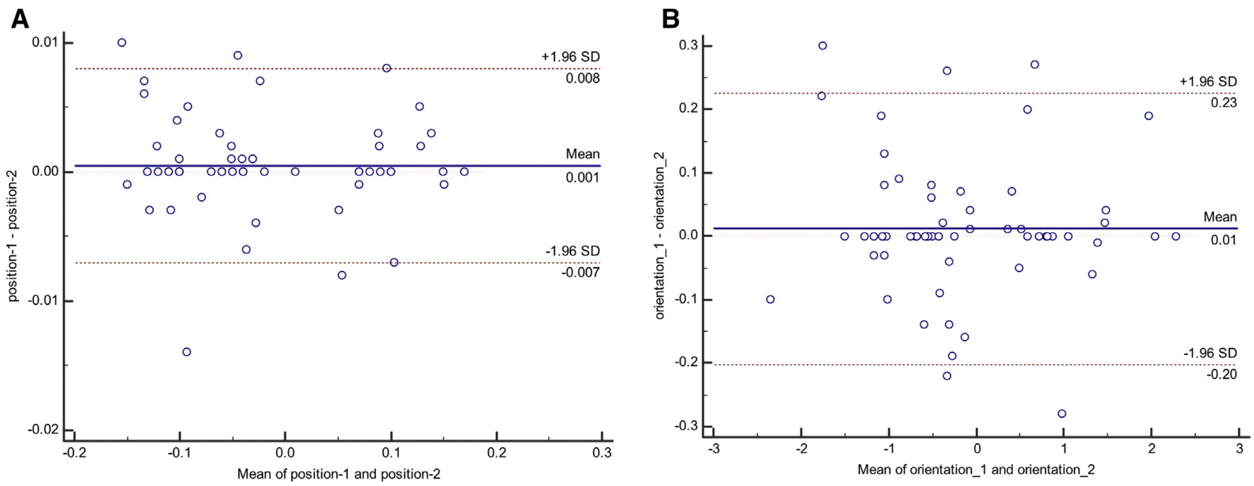

Fig 4. Bland-Altman plot for repeated measurement of translations (**A**) and orientations (**B**).

Table I. Difference between the simulative bracket position and the postoperative bracket position

		Dimension											
		Mesiodistal (mm)		*Buccolingual (mm)*		*Vertical (mm)*		*Torque (°)*		*Angulation (°)*		*Rotation (°)*	
Tooth type	*n*[*]	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Incisor	71	0.013[†]	0.079	0.123	0.064	−0.088	0.041	−0.371	0.742	0.061	0.660	0.014	0.821
Canine	36	0.016	0.097	0.033	0.126	−0.083	0.041	0.343	1.152	0.087	0.912	−0.007	0.909
Premolar	62	0.001	0.099	−0.031	0.152	−0.089	0.049	0.794	1.359	0.078	0.823	−0.064	0.986
Molar	36	0.007	0.094	0.125	0.087	−0.091	0.054	0.690	1.473	0.060	0.900	0.047	0.906
Total	205	0.009	0.091	0.060	0.131	−0.087	0.047	0.286	1.276	0.061	0.806	−0.015	0.903

Mean, Mean value of error N; *SD*, standard deviation.
*n is number of brackets used for analysis; [†]Positive values indicate a postoperative position more mesial, buccal, gingival, or with more lingual crown torque, more distal angulation, or a lingual surface rotated more mesially than in the simulative position.

recent years, a variety of devices or transfer trays have been developed to accurately transfer the ideal bracket placement to patients' dentitions.[2,4,6-9,12,13,15-17] However, the effectiveness of such devices might be questioned without proper procedures for precise control and prediction of possible complications. Based on the 3D assessment, we found that the protocol in this study allowed accurate transfer of bracket placement. Both the guiding device and precise intraoperative control are necessary to achieve accuracy.

Accurate measurement is necessary for an objective result. With the advance of digital technology, 3D assessment using the scanned model has been proposed to be more accurate than 2D assessment using digital photography.[5,13-15,18] In this study, a semiautomated 3D measurement in Geomagic Studio 2013 was used to measure the position and orientation deviations for 205 brackets. Because the local coordinate system had been prelocated on the bracket, there was no need to identify the corresponding reference points on the teeth from different patients repeatedly. This method minimized measurement errors and measured the position deviation and orientation deviation within an error between −0.010 and 0.010 mm and −0.30° and 0.28°, respectively.

In traditional indirect bonding techniques, the standard operation of placing and pressing the transfer tray on the dentition were introduced to transfer the bracket to the patient's dentition.[2,4,6-9] This procedure is simple, with additional advantages in reducing chair time as well as clinical fatigue, and increasing patient comfort.[2,4,6-8,19,20] However, errors may occur because of fabrication errors, contaminants or involvement of soft tissue, varied thickness of the bonding materials, limited access to hold the transfer tray in the posterior region, or varying finger pressure on the tray.[13,16] This technique requires a significant learning curve and much experiences to assess whether the transfer tray is accurately fabricated and fits the dentitions well before

Table II. The frequencies of directional bias resulting from the guided bonding method

		Dimension											
		Mesiodistal		*Buccolingual*		*Vertical*		*Torque*		*Angulation*		*Rotation*	
Tooth type	*n**	*Mesial (%)*	*Distal (%)*	*Buccal (%)*	*Lingual (%)*	*Occlusal (%)*	*Gingival (%)*	*BCT (%)*	*LCT (%)*	*MRT (%)*	*DRT (%)*	*m-b (%)*	*m-l (%)*
Incisor	71	56.34[†]	43.66	94.37	5.63	94.37	5.63	70.42	29.58	46.48	53.52	50.70	49.30
Canine	36	55.56	44.44	61.11	38.89	91.67	8.33	36.11	63.89	41.67	58.33	50.00	50.00
Premolar	62	45.90	54.10	27.87	72.13	91.80	8.20	29.51	70.49	39.34	60.66	49.18	50.82
Molar	36	51.43	48.57	85.71	14.29	88.57	11.43	31.43	68.57	45.71	54.29	45.71	54.29
Total	205	52.20	47.80	66.83	33.17	91.71	8.29	45.37	54.63	43.90	56.10	49.76	50.24

BCT, buccal crown torque; *LCT*, lingual crown torque; *MRT*, mesial root tip; *DRT*, distal root tip; *m-b*, mesiobuccal; *m-l*, mesiolingual.
*n is number of brackets used for analysis; [†]Results are expressed as percentages.

use, as well as to control the transfer tray in complete seating and the bracket in the predetermined position during the bonding in vivo.[13,16,21,22]

With the advance of digital technology in indirect bonding techniques, it is possible to fabricate the transfer tray efficiently and accurately with rapid prototyping, to optimize bracket position on software, as well as to facilitate communications among doctors, technicians, and patients.[9-12,14] There are 2 major types of transfer trays fabricated using digital techniques.[10] One is made using a traditional polyvinyl siloxane, pressure, or vacuum-forming materials on a 3D printed bracket transfer model. The other is directly printed using a 3D printer, which eliminates the need to print the bracket transfer model, bringing substantial time and cost savings depending on the 3D printer used.[9,11,12,14] However, these printed transfer trays must meet a strict requirement. The tray must have the exact physical dimensions of the bracket and with sufficient retention of the bracket, but able to be easily removed without risk of the brackets debonding on removal. In other words, less space designed between the bracket and the tray brings better retention and accuracy, making the tray more difficult to be removed, whereas more space negatively affects the retention and accuracy.[10,14]

Therefore, to simplify the fabrication process, besides taking advantage of rapid prototyping, the guided bonding device was designed with an L-shaped guide without considering the space designed between the bracket and the tray. Moreover, a protocol was introduced to help control bracket placement. In our study, the rapid prototyping technique allowed accurate and efficient fabrication of the guided bonding device. Before bonding, it was possible to visually check the suitability of the device on both a stone model and on the patient's dentition. During bonding, the buccolingual position of the bracket was ensured by the direct bonding procedures, and the mesiodistal and the vertical position of the bracket were guided by the distal and occlusal guides, respectively. As a result, except for 15.12% brackets with torque deviation over 2°, the deviations in mesiodistal, buccolingual, vertical, rotation, and angulation were under the clinically acceptable range (0.5 mm in translation or 2° in orientation) for all brackets.

Although the results were encouraging, the frequencies of directional bias cannot be ignored. In the vertical orientation, most brackets were more occlusally positioned in the 4 tooth types (incisor 94.37%, canine 91.67%, premolar 91.80%, and molar 88.57%). One assumption is that the device might not fit the dentition as well as we observed visually. The tiny error in the data acquisition and the fabrication might prevent the guided bonding device from being completely seated over the dentition. A possible modification is to increase the space between the device and the dentition in the design process. The increased space might tolerate errors and make it possible for complete seating of the device. But further study is required to identify the exact magnitude of the space.

Another interesting finding was that the frequencies of directional bias for buccolingual translation and torque varied in the 4 tooth types. For buccolingual translation, most of the incisors (94.37%), canines (61.11%), and molars (85.71%), but only 27.87% of premolars, were in a more buccal position. For torque, most of the incisors (70.42%), but only 36.11% canines, 29.51% premolars, and 31.43% molars had more buccal crown torque. However, the directional bias for buccolingual translation and torque were found to be similar in the 4 tooth types in a report by Grünheid et al[13] using vinyl polysiloxane trays. For buccolingual translation, most of the teeth are found in a more buccal position (incisor 81.48%, canine 76.92%, premolar 80.43%, and molar 70.00%). For torque, no exact trends were found in the directional bias regarding the 4 tooth types.

A possible explanation is that the bracket bases varied in the study by Grünheid et al[13] and in this study before bonding. In the study by Grünheid et al, the bracket base was customized with adhesive paste in the process of bonding brackets on a stone model, whereas in our study, the adhesive paste on the bracket base was simulated on a computer rather than actually bonded on the model. The anatomical variations in tooth morphology considered, the virtual bonding may vary from the actual bonding. This difference would further influence the position of bracket using the guided bonding device. In spite of this, torque deviation was found to be in a small range, from -2.93° to 3.16°, which might not be occur in lengthy orthodontic treatment with different types of tooth movement and could be easily prevented with wire bending.

Besides the accuracy of bracket positioning, bracket failure is another important factor affecting clinical efficiency in fixed appliance orthodontic treatment.[23] In this study, no bracket was lost during the removal of the guided bonding device or in the 3-month follow-up. This result can be explained by many reasons. Firstly, the collision between the brackets and the opposite dentition had been validated and inhibited in the process of digital bracket positioning, which decreased the possibility of bracket collision after actual bracket bonding. Secondly, this device had the advantage of direct bonding during bracket placement. The advantages of direct bonding over indirect bonding might be that (1) the bracket base fitted closer to the tooth surface, (2) it was easier to work clean and to remove excess adhesive flash around the bracket bases, and (3) the bonding adhesive constantly filled out the entire contact surface.[19] Thirdly, the 3 features (Figs 2 and 4) of the device eliminated the undercuts between the device and the brackets, which helped easy removal of the device without affecting the bracket bonding. Fourthly, all patients enrolled in the study were adults and had good compliance.

Compared with traditional direct bonding techniques, the most significant advantage of this device is that the guided bonding device could help the operator achieve accurate bracket placement on dentition resembling the virtual bonding process, which was an essential procedure in computer-assisted orthodontic treatment. In traditional direct bonding techniques, bracket placement is based on the facial axis point, predetermined bonding heights, or the preference of the operator. The outcome of bracket placement could only be visually observed and further adjusted when the teeth were actually aligned. However, the virtual bonding process makes it possible to provide an estimated alignment of the patient's teeth with the given bracket choice and prescription based on the archwire slots aligned with an imaginary archwire, which predicts the possible treatment outcome and enhances the bracket position before bonding.[10] In the guided bonding technique, the position of the bracket was determined by the virtual bonding process, and the proposed device was found to be accurate in achieving a bracket placement resembling the virtual bonding process, which might benefit personalized and predictable orthodontic treatment. Furthermore, the bonding procedure in this technique had a feasible protocol for bracket control, which requires less experience and can be performed by an orthodontic auxiliary.

Another consideration is the chair time for patients during the guided bonding process. Because this technique resembles the direct bonding technique, it might take more chair time than the indirect bonding technique. However, according to our experience, it took about 15 to 20 minutes to complete the bonding procedures for both the maxilla and mandible in this study. In a study by Yıldırım and Saglam-Aydinatay,[24] the clinical time for indirect bonding was 26.51 ± 3.33 minutes. Bozelli et al[25] reported that the clinical time for indirect bonding was 12.68 minutes for the whole mouth. The difference of chair time between this study and previous studies might not be clinically significant. The short chair time was because of 3 possible reasons. Firstly, the bracket was guided by the L-shaped guides, which decreased the duration of adjusting bracket position in traditional direct bonding techniques. Secondly, the flash-free adhesive system used in our study decreased the bonding time and reduced the excess of adhesive around the brackets.[26,27] Thirdly, because of the features of eliminating undercuts between the dentition and the device, the device in this study could be easily removed after bonding, which might be easier than removing the outer and inner layers of the transfer tray in traditional indirect bonding technique.[24,25]

One limitation of this protocol was that the placement and adjustment of buccal tubes on molars require the use of an oral mirror, which could influence the convenience of the operation. Further studies should focus on the effectiveness and efficiency of computer-assisted orthodontic treatment to achieve predicted outcomes using the proposed guided bonding device, as well as the customized brackets, robot-bent wires, and the predesigned orthodontic procedure.

CONCLUSION

Based on computer-aided design and computer-aided manufacturing–guided bonding device and precise control, this protocol transferred the planned bracket position from a digital setup to the patient's dentition with generally high positional accuracy.

ACKNOWLEDGMENT

The guided bonding device and the fabrication process in this study are protected by a license of invention patent (No. 201610142088.X) in People's Republic of China. This study was supported financially by the Project of Science and Technology Support Program of Sichuan Province, China (Grant No. 2014SZ0157) and the Project of Science and technology innovation program of Sichuan Province, China (Grant No. 2017037).

REFERENCES

1. Shpack N, Geron S, Floris I, Davidovitch M, Brosh T, Vardimon AD. Bracket placement in lingual vs labial systems and direct vs indirect bonding. Angle Orthod 2007;77:509-17.
2. Silverman E, Cohen M, Gianelly AA, Dietz VS. A universal direct bonding system for both metal and plastic brackets. Am J Orthod 1972;62:236-44.
3. Kalange JT. Prescription-based precision full arch indirect bonding. Semin Orthod 2007;13:19-42.
4. Koga M, Watanabe K, Koga T. Quick indirect bonding system (quick IDBS): an indirect bonding technique using a double-silicone bracket transfer tray. Semin Orthod 2007;13:11-8.
5. Schmid J, Brenner D, Recheis W, Hofer-Picout P, Brenner M, Crismani AG. Transfer accuracy of two indirect bonding techniques-an in vitro study with 3D scanned models. Eur J Orthod 2018;40:549-55.
6. Thomas RG. Indirect bonding: simplicity in action. J Clin Orthod 1979;13:93-106.
7. Sondhi A. Effective and efficient indirect bonding: the Sondhi method. Semin Orthod 2007;13:43-57.
8. Moskowitz EM. Indirect bonding with a thermal cured composite. Semin Orthod 2007;13:69-74.
9. Ciuffolo F, Epifania E, Duranti G, De Luca V, Raviglia D, Rezza S, et al. Rapid prototyping: a new method of preparing trays for indirect bonding. Am J Orthod Dentofacial Orthop 2006;129:75-7.
10. Christensen LR, Cope JB. Digital technology for indirect bonding. Semin Orthod 2018;24:451-60.
11. El-Timamy AM, El-Sharaby FA, Eid FH, Mostafa YA. Three-dimensional imaging for indirect-direct bonding. Am J Orthod Dentofacial Orthop 2016;149:928-31.
12. Son KH, Park JW, Lee DK, Kim KD, Baek SH. New virtual orthodontic treatment system for indirect bonding using the stereolithographic technique. Korean J Orthod 2011;41:138.
13. Grünheid T, Lee MS, Larson BE. Transfer accuracy of vinyl polysiloxane trays for indirect bonding. Angle Orthod 2016;86:468-74.
14. Kim J, Chun YS, Kim M. Accuracy of bracket positions with a CAD/CAM indirect bonding system in posterior teeth with different cusp heights. Am J Orthod Dentofacial Orthop 2018;153:298-307.
15. Schubert K, Halbich T, Jost-Brinkmann PG, Müller-Hartwich R. Precision of indirect bonding of lingual brackets using the Quick Modul System (QMS)®. J Orofac Orthop 2013;74:6-17.
16. Castilla AE, Crowe JJ, Moses JR, Wang M, Ferracane JL, Covell DA Jr. Measurement and comparison of bracket transfer accuracy of five indirect bonding techniques. Angle Orthod 2014;84:607-14.
17. Garino F, Garino GB. Computer-aided interactive indirect bonding. Prog Orthod 2005;6:214-23.
18. Nichols DA, Gardner G, Carballeyra AD. Reproducibility of bracket positioning in the indirect bonding technique. Am J Orthod Dentofacial Orthop 2013;144:770-6.
19. Zachrisson BU, Brobakken BO. Clinical comparison of direct versus indirect bonding with different bracket types and adhesives. Am J Orthod 1978;74:62-78.
20. Aguirre MJ, King GJ, Waldron JM. Assessment of bracket placement and bond strength when comparing direct bonding to indirect bonding techniques. Am J Orthod 1982;82:269-76.
21. Keim RG. The indirect approach. J Clin Orthod 2007;41:651-2.
22. Sheridan JJ. The Readers' Corner. 1. Do you use indirect bonding? J Clin Orthod 2004;38:543-4.
23. Beckwith FR, Ackerman RJ Jr, Cobb CM, Tira DE. An evaluation of factors affecting duration of orthodontic treatment. Am J Orthod Dentofacial Orthop 1999;115:439-47.
24. Yıldırım K, Saglam-Aydinatay B. Comparative assessment of treatment efficacy and adverse effects during nonextraction orthodontic treatment of Class I malocclusion patients with direct and indirect bonding: a parallel randomized clinical trial. Am J Orthod Dentofacial Orthop 2018;154:26-34.e1.
25. Bozelli JV, Bigliazzi R, Barbosa HA, Ortolani CL, Bertoz FA, Faltin Junior K. Comparative study on direct and indirect bracket bonding techniques regarding time length and bracket detachment. Dent Press J Orthod 2013;18:51-7.
26. Foersch M, Schuster C, Rahimi RK, Wehrbein H, Jacobs C. A new flash-free orthodontic adhesive system: a first clinical and stereomicroscopic study. Angle Orthod 2016;86:260-4.
27. Grünheid T, Larson BE. Comparative assessment of bonding time and 1-year bracket survival using flash-free and conventional adhesives for orthodontic bracket bonding: a split-mouth randomized controlled clinical trial. Am J Orthod Dentofacial Orthop 2018;154:621-8.