Original Article

Transfer accuracy of vinyl polysiloxane trays for indirect bonding

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ABSTRACT

Objective: To elicit the magnitude, directional bias, and frequency of bracket positioning errors caused by the transfer of brackets from a dental cast to the patient's dentition in a clinical setting.

Materials and Methods: A total of 136 brackets were evaluated. The brackets were placed on dental casts and scanned using cone beam computed tomography (CBCT) to capture 3-D positioning data. The brackets were then transferred to the patient's dentition with an indirect bonding method using vinyl polysiloxane (VPS) trays and later scanned using CBCT to capture the final bracket positioning on the teeth. Virtual models were constructed from the two sets of scan data and digitally superimposed utilizing best-fit, surface-based registration. Individual bracket positioning differences were quantified using customized software. One-tailed *t* tests were used to determine whether bracket positioning was within limits of 0.5 mm in the mesiodistal, buccolingual, and vertical dimensions, and 2° for torque, tip, and rotation.

Results: Individual bracket positioning differences were not statistically significant, indicating, in general, final bracket positions within the selected limits. Transfer accuracy was lowest for torque (80.15%) and highest for mesiodistal and buccolingual bracket placement (both 98.53%). There was a modest directional bias toward the buccal and gingival.

Conclusion: Indirect bonding using VPS trays transfers the planned bracket position from the dental cast to the patient's dentition with generally high positional accuracy. (*Angle Orthod.* 2016;86:468–474.)

KEY WORDS: Transfer accuracy; Indirect bonding; Bracket

INTRODUCTION

Since the advent of preadjusted edgewise appliances, orthodontists have striven to improve the efficiency of aligning teeth with minimal wire bending. The use of preadjusted appliance systems is based on the concept that ideal bracket placement will allow correction of tooth positions in all three planes of space with the placement of straight archwires.[1–4] For this reason, accurate bracket positioning is of critical importance in realizing the full potential of preadjusted edgewise appliances.

The placement of orthodontic brackets on the patient's dentition is typically accomplished by either a direct or an indirect bonding method. The direct method is a one-stage procedure during which the brackets are placed directly onto the patient's teeth. In contrast, the indirect method is a two-stage procedure: In the first stage, the brackets are placed onto a dental cast of the patient's teeth; in the second stage the brackets are transferred from the cast to the patient's teeth using custom-made trays or jigs. Since Silverman et al.[5] first described an indirect bonding method in 1972, this approach has increased in popularity due to some significant advantages such as unimpaired visibility during bracket positioning, improved patient comfort, and reduced chair time.[6–9] Most importantly, it has been suggested that with the indirect method, the brackets can be placed more accurately[10] because the positioning is completed away from many of the clinical constraints and variables that complicate the direct method such as moisture control, patient management, or a hurried schedule.

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Figure 1. Vinyl polysiloxane transfer trays for indirect bonding.

A drawback of indirect bonding is that positioning of the brackets on the dental cast may not be reliably transferred to the patient's dentition. For example, it is conceivable that contaminants or soft tissue interferences could affect the transfer. Moreover, the thickness of bonding material between the brackets and teeth during clinical bonding might vary and thus affect final bracket positioning. Finally, errors in tray fabrication or clinical technique may result in bracket positioning errors during the transfer.

The uncertainties inherent in the transfer process could present a problem for clinicians who use the indirect method because bracket positioning has a direct influence on both the magnitude and direction of tooth movement. Improperly positioned brackets cause inefficiencies in leveling and alignment, and may lead to longer treatment times or poorer results. While the advantages of indirect bonding are well described,[9,11] objective evidence regarding the transfer accuracy during clinical application is limited. For this reason, the present study measured the positional accuracy of an indirect bonding technique for orthodontic brackets in vivo.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board at the University of Minnesota (Study 1109E04701). One hundred sixty-three brackets bonded to eight subjects, six female and two male, receiving orthodontic treatment at the University of Minnesota, were initially included in the study. All subjects presented with mild crowding or spacing; a representative malocclusion is shown in Figure 1. Over the course of the study, 27 brackets were excluded for the following reasons: bond failure, repositioning prior to imaging, or software errors. Therefore, a total of 136 brackets were evaluated.

Alginate impressions were taken of each subject's dentition. The impressions were poured in green die stone (Modern Materials Die Keen, Hanau, Germany) to fabricate dental casts. Separator fluid was applied to the casts and allowed to dry. Preadjusted edgewise twin brackets were then placed on the casts with a light-cure composite adhesive (Transbond XT Light Cure Adhesive, 3M Unitek, Monrovia, Calif). The brackets were positioned at the center of the clinical crown of each tooth. Various bracket systems and slot sizes were used depending on the treating clinician's preference. After bracket placement, the adhesive was cured in a light-cure box (Maxi-Light, Select Dental, Farmingdale, NY) for 5 minutes. Cone beam computed tomography (CBCT) scans of the casts were then obtained with an i-CAT Next Generation (Imaging Sciences International, Hatfield, Pa) at a voxel size of 0.2 mm^3, field of view of 8 $\times$ 16 cm, scan time of 26.9 seconds, tube voltage of 120 kV, and tube current of 37.07 mA.

After the scans, vinyl polysiloxane (VPS) putty (Express STD, 3M ESPE, St Paul, Minn) was mixed, applied over the cast teeth and brackets, and allowed to set. The casts were then soaked in warm water for 20 minutes, and the putty carefully removed so that the brackets became detached from the cast and remained embedded in the putty matrix. The putty trays were then placed back into the light-cure box for an additional 5 minutes to ensure complete polymerization of the adhesive on the bracket bases. The trays were then trimmed to a thickness of 2–3 mm, sectioned at the midline, and cleaned with alcohol (Figure 1). All trays were fabricated by the same operator.

The brackets were bonded using the indirect method, as follows. The subjects' teeth were polished using a fluoride-free prophylaxis paste (Topex

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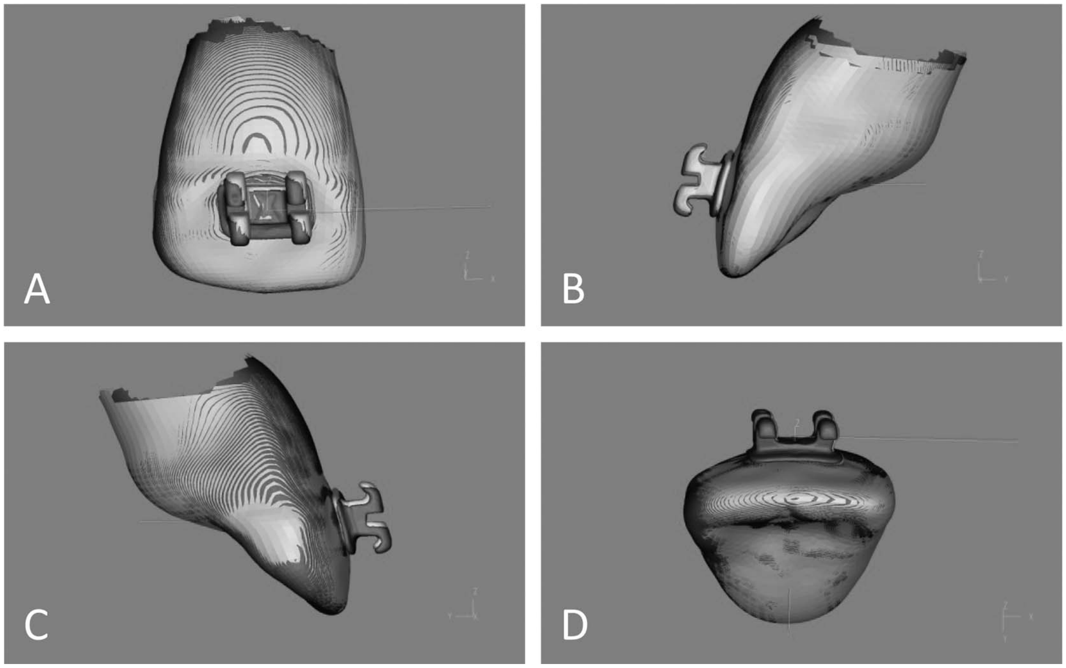

Figure 2. Best-fit superimposition of 3-D virtual surface models of corresponding teeth to determine differences in bracket position between setup and clinical situation. (A) buccal view; (B) mesial view; (C) distal view; (D) incisal view.

Prep&Polish, Sultan Healthcare, Hackensack, NJ) in a rubber cup attached to a low-speed handpiece for 5 seconds, rinsed with water, and dried thoroughly with oil and moisture-free air. The buccal surfaces were then etched with 35% phosphoric acid (Temrex, Freeport, NY) for 30 seconds, rinsed with water for 30 seconds to ensure complete removal of the etchant, and then air-dried until they appeared dull and frosty. A chemical-cure composite sealant (Maxcure, Reliance Orthodontic Products, Itasca, Ill) was mixed and applied to the etched tooth surfaces as well as to the individualized bracket bases. The transfer trays were then seated over the teeth, one quadrant at a time, held in place with firm finger pressure for 2 minutes, and left in place for an additional 8 minutes without finger pressure to allow complete curing of the sealant. The trays were then carefully removed from the teeth. Any brackets that detached from the teeth during tray removal were excluded from the study and rebonded without using the transfer trays. Four orthodontic residents performed the bonding procedures.

All subjects were treated using SureSmile (OraMetrix, Richardson, Tex), an all-digital orthodontic CAD/CAM system, which combines 3-D imaging, treatment planning software, and robotically bent archwires.[12] At time points determined by each treating clinician, CBCT scans of the subjects' dentitions were obtained with an i-CAT Next Generation at settings identical to those described for the dental casts, to fabricate the SureSmile therapeutic models and the robotically bent archwires. These same scans were used to localize the brackets on each subject's teeth and compare with the location of the brackets in the corresponding indirect setup as detailed below. As the CBCT scans were taken as part of the SureSmile process, the subjects were not exposed to any additional radiation for study purposes.

For each patient, two 3-D virtual surface models were created from the CBCT scan data. The first model represented the stone cast setup while the second model represented the patient's dentition with brackets bonded to the teeth. Each tooth was digitally sectioned to allow modeling as an independent unit. The corresponding teeth on both models were then digitally superimposed using a customized tool within emodel 9.0 software (Geodigm, Falcon Heights, Minn) as described in detail elsewhere.[13] In brief, an iterative closest point–matching algorithm was used to achieve surface feature–based, best-fit superimposition of the tooth derived from the second scan on the tooth derived from the first scan, which was considered the reference (Figure 2). To ensure that superimposition was based solely on tooth-surface features, the soft tissue was removed from the digital models and the brackets were isolated. After superimposition, the emodel software provided an output of any differences in bracket position between setup and clinical situation, as a result of the indirect bonding procedure. These differences included both magnitude and direction, and were reported in six dimensions, that is, mesiodistal, buccolingual, and vertical linear differences as well as torque, tip, and rotation angular differences. All superimpositions were performed by the same operator.

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Table 1. Bland-Altman Analyses Performed to Assess Repeatability for Each Dimension of Tooth Movement

Dimension	n[a]	Bias	Lower Limit of Agreement	Upper Limit of Agreement
Mesiodistal (mm)	26	0.010	−0.095[b]	0.116
Buccolingual (mm)	26	0.009	−0.074	0.093
Vertical (mm)	26	0.008	−0.157	0.173
Torque (°)	26	−0.281	−2.479	1.917
Tip (°)	26	0.193	−1.400	1.787
Rotation (°)	26	0.042	−1.214	1.299

[a] n indicates number of brackets used for analysis.

[b] Negative values indicate a difference with a final bracket position more distal, lingual, or apical, or with less buccal crown torque, less mesial tip, or a facial surface rotated more distally than in the indirect setup.

Linear differences of ≤0.5 mm and angular differences of ≤2° were considered clinically acceptable, whereas those >0.5 mm or 2° were considered clinically unacceptable. These limits were selected as they represent professional standards: During case evaluation using the American Board of Orthodontics objective grading system, points are subtracted for teeth that deviate 0.5 mm or more from proper alignment in the categories "alignment" and "marginal ridges."[14] A crown-tip inadequacy of 2° causes a marginal ridge discrepancy of 0.5 mm in an average-sized molar.

After a washout period of 3 weeks, 26 tooth pairs were randomly selected from the original sample and the measurements repeated to assess repeatability.

Statistical Analysis

Repeatability was assessed as the degree of agreement of measurements on replicate specimens using the method described by Bland and Altman.[15] The biases were computed as the average of the differences for each dimension. One-tailed *t* tests with a 95% confidence interval were performed on the absolute value of each difference measurement with respect to the six dimensions evaluated to determine whether the differences were within the limits of 0.5 mm for mesiodistal, buccolingual, and vertical differences, and 2° for torque, tip, and rotation. Frequency statistics were computed to describe the directionality and frequency of error resulting from the bracket transfer during indirect bonding. The frequency biases were calculated separately for each tooth type (incisors, canines, premolars, molars) as well as for the complete data set. Statistical analyses were performed using R Statistical Software 2.9.2 (R Foundation for Statistical Computing, Vienna, Austria). *P* values of less than .05 indicated differences within the selected limits of 0.5 mm for linear measurements and 2° for angular measurements.

RESULTS

Repeatability assessments are reported in Table 1. Bland-Altman analyses of agreement between measurements of individual bracket positions performed at two time points yielded mean differences ranging from 0.008 mm to 0.010 mm for linear measurements and from −0.281° to 0.193° for angular measurements.

Differences between final bracket positions and those in the indirect setup are shown in Table 2. All one-sided *t* tests reached statistical significance ($P < .05$), indicating, in general, final bracket positions within the selected limits of 0.5 mm for linear measurements and 2° for angular measurements. The exact frequencies for each tooth type are shown in Table 3. The transfer accuracy was lowest for torque (80.15%), while it was highest for mesiodistal and buccolingual bracket placement (both 98.53%). The frequencies of directional bias resulting from indirect bonding are shown in Table 4.

DISCUSSION

Indirect bonding methods have been developed to aid the orthodontist in placing brackets accurately without many of the clinical challenges experienced

Table 2. Differences Between Final Bracket Position and Bracket Position in Indirect Setup for Each Tooth Type

		Dimension					
Tooth Type	n[a]	Mesiodistal (mm)	Buccolingual (mm)	Vertical (mm)	Torque (°)	Tip (°)	Rotation (°)
Incisor	54	−0.012 ± 0.009[b,c]	−0.054 ± 0.041	0.026 ± 0.013	0.103 ± 0.085	0.061 ± 0.005	0.235 ± 0.010
Canine	26	0.013 ± 0.009	−0.053 ± 0.031	0.034 ± 0.005	−0.228 ± 0.050	−0.198 ± 0.055	0.210 ± 0.000
Premolar	46	−0.380 ± 0.003	−0.492 ± 0.062	0.216 ± 0.053	0.401 ± 0.415	−0.047 ± 0.145	−0.040 ± 0.010
Molar	10	−0.063 ± 0.033	−0.045 ± 0.074	0.035 ± 0.017	−0.268 ± 0.520	−0.213 ± 0.445	0.405 ± 0.335
Total	136	−0.007 ± 0.117	−0.001 ± 0.131	−0.025 ± 0.160	−0.120 ± 1.757	−0.159 ± 1.574	−0.197 ± 1.374

[a] n indicates number of brackets used for analysis.

[b] Negative values indicate a final bracket position more distal, lingual, or apical, or with less buccal crown torque, less mesial tip or a facial surface rotated more distally than in the indirect setup.

[c] Results are expressed as mean values ± standard deviations.

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Table 3. Frequencies of Final Bracket Position Within the Selected Limits of 0.5 mm for Linear Measurements and 2° for Angular Measurements for Each Tooth Type

		Dimension					
Tooth Type	n[a]	Mesiodistal	Buccolingual	Vertical	Torque	Tip	Rotation
Incisor	54	100[b]	100	96	85	89	87
Canine	26	100	100	100	92	92	88
Premolar	46	98	96	96	70	85	87
Molar	10	90	100	100	70	50	90
Total	136	98.53	98.53	97.06	80.15	85.29	87.50

[a] n indicates number of brackets used for analysis.
[b] Results are expressed as percentages.

with direct bonding.[5,6] The present results provide insight into the positional accuracy resulting from the transfer of brackets from the indirect cast setup to the patient's teeth in several ways: the direction and frequency of bonding errors as well as how frequently the brackets "hit the target" and are placed within clinically acceptable limits. Moreover, the results may shed new light on several widely held assumptions regarding the pattern of indirect bonding errors.

One of these assumptions is that posterior brackets have a higher incidence of positioning error. In this study, brackets on premolars and molars showed a slightly higher frequency of positioning outside the clinically acceptable limits than they did on incisors and canines. Although the difference between anterior and posterior teeth was not statistically significant, there was a trend toward an increase in directional bias in the posterior areas of the mouth with brackets on molars being the most directionally biased. A possible explanation for this finding is the difficulty of holding a transfer tray as precisely and steadily in the molar region as in other areas of the mouth because of decreased access. The finding may also be partially explained by the relatively small sample size of molar brackets in this study. Small sample sizes allow for small amounts of random error to significantly affect results and clinical interpretation.

Another assumption held by some clinicians is that most vertical positioning errors are biased toward the occlusal because incompletely seating the transfer tray is seemingly more likely than overseating it during the clinical bonding procedure. However, our data suggest the opposite; most vertical errors occurred as placement more gingivally. Gingival positioning errors might result from stretching the transfer tray by finger pressure during bonding. The VPS trays used in the present study have elastic properties and thus absolute rigidity during seating cannot be assumed. In addition, if a tray's occlusal coverage was not adequate, the tray may have slid facially and gingivally under the operator's finger pressure.

A third assumption is that there may be a bias toward the buccal as a consequence of the amount of adhesive applied to the brackets and teeth during the clinical bonding procedure. In the present study, this bias was observed in 79% of the brackets, which were positioned more buccally than intended. In the other 21%, which were more lingually positioned, it is possible that portions of the composite on the bracket base were thinned or lost during the laboratory procedure after the first CBCT scan, that is, tray removal from the stone cast and cleaning of the customized bracket bases. If the entire composite on the bracket base is lost before bonding, these brackets may fail.

A few comments must be made on the methodology used in our study. The multioperator nature of the clinical bonding procedure might have caused more variation than would a single-operator protocol. Moreover, the operators were orthodontic residents with

Table 4. Frequencies of Directional Bias Resulting from the Indirect Bonding Method

		Dimension											
		Mesiodistal		Buccolingual		Vertical		Torque		Tip		Rotation	
Tooth Type	n[a]	Mesial	Distal	Buccal	Lingual	Occlusal	Gingival	BCT[b]	LCT	MRT	DRT	m-b	m-l
Incisor	54	44.44[c]	55.56	81.48	18.52	42.59	57.41	48.15	51.85	50.00	50.00	50.00	50.00
Canine	26	53.85	46.15	76.92	23.08	38.46	61.54	57.69	42.31	57.69	42.31	50.00	50.00
Premolar	46	50.00	50.00	80.43	19.57	39.96	63.04	58.70	41.30	56.52	43.48	50.00	50.00
Molar	10	30.00	70.00	70.00	30.00	40.00	60.00	60.00	40.00	70.00	30.00	40.00	60.00
Total	136	47.06	52.94	79.41	20.59	39.71	60.29	54.41	45.59	55.15	44.85	49.26	50.74

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

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limited clinical experience and, as with any method, the level of experience could have influenced bonding accuracy. Conversely, it can be argued that the study design used makes the results more generalizable as the indirect bonding procedure must work in the hands of multiple operators. Mathematical superimposition of digital dental models allowed quantification of differences between final bracket position and bracket position in the indirect setup to the nearest 1 μm. Modeling each tooth/bracket pair as an independent unit made any changes in relative tooth position between the bonding appointment and the CBCT scan irrelevant. Assuming accurate impressions, stone casts and CBCT scans, absence of acute enamel attrition, interproximal stripping, or dental pathology that could alter tooth shape, the tooth surfaces were identical from the first 3-D surface model to the second.

Comparing the present results with those of other studies is complicated by the fact that most studies investigating the accuracy of indirect bonding have made their comparisons with the direct bonding method or to a predetermined "ideal" bracket position: typically the center of the clinical crown as prescribed by many preadjusted appliances. For instance, a study by Aguirre et al. found that neither a direct nor an indirect bonding method was completely accurate with regard to linear or angular placement of brackets compared with an ideal.[10] Similarly, a study using a photographic method to evaluate the accuracy of direct and indirect bracket placement found neither method to be error free, with no significant differences between the mean errors produced by the two methods of bracket placement.[16]

More recently, two studies quantified differences in bracket position resulting from the bracket transfer using an in vitro design.[17,18] Brackets were transferred from initial working stone models, to which the brackets were bonded, to final "patient" models. Using 3-D image superimposition to measure transfer discrepancies along three axes, Wendl et al. found deviations of 0.15 mm on the x-axis, 0.17 mm on the y-axis, and 0.19 mm along the z-axis.[17] Comparing the bracket transfer accuracy of five indirect bonding techniques with a photographic method, Castilla et al. found linear differences to range from 0.06 mm to 0.49 mm.[18] Although some of the deviations observed in those in vitro studies were larger than those found in the present one, the mean error values observed in both studies were still within the clinically acceptable limits as defined in this study.

Together with the results of the present in vivo study, these data provide evidence that, in general, the transfer of brackets from the indirect bonding setup to the patient's dentition has a high positional accuracy. However, there are some positioning errors outside the chosen limits and errors may be additive. For instance, if a bracket is off by 0.5 mm in one direction and an adjacent bracket is off by 0.5 mm in the opposite direction, the resulting discrepancy could be up to 1 mm. This necessitates individual clinicians to determine whether they are willing to accept these errors as they consider indirect bonding within their practice.

CONCLUSION

- In general, the indirect bonding transfer process with VPS trays results in bracket placement in clinically acceptable positions with high positional accuracy and a mild buccal and gingival bias for all tooth types.

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