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Original article

Transfer accuracy of two indirect bonding techniques—an *in vitro* study with 3D scanned models

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Summary

Background and objectives: Indirect bonding (IDB) proved to be an effective method for appropriate bracket positioning in patients. Different methods and materials are available for fabricating transfer trays. This *in vitro* study was designed to measure and compare the transfer accuracy of two common IDB methods.

Materials and methods: Sixty stone models were fabricated and separated in two groups of 30 models each (15 working models, 15 patient models). After placing brackets on the working models, 30 IDB trays were made: 15 silicone (method I) and 15 double-vacuum forms (method II). With these trays, the brackets were transferred to the patient models. The bracket positions were scanned before and after the IDB procedure with an intraoral scanner. The linear and angular discrepancies were then determined digitally by measuring six different dimensions: occluso-cervical, mesio-distal, bucco-lingual, tip, rotation, and torque.

Results: The silicone trays showed fewer transfer discrepancies, on average, in all measured dimensions. There were significant differences between the methods in the occluso-cervical ($P < 0.001$), mesio-distal ($P = 0.001$), and torque ($P = 0.044$) dimensions. With both methods, 100 per cent of the horizontal and transversal measurements of both methods were within the clinically acceptable range of 0.25 mm. With method I, 98.5 per cent of the vertical and 95.9 per cent of the angular measurements were within the range of 0.25 mm and 1°, respectively. With method II, 94 per cent of the vertical and 84.8 per cent of the angular measurements were within the clinically acceptable range.

Conclusions: Although both transfer methods showed a high precision, silicone trays scored better in terms of accuracy than double-vacuum forms.

Introduction

Precise bracket positioning is an important factor in fixed orthodontics to minimize the need for arch-wire bending and bracket repositioning. In 1972, indirect bonding (IDB) was described by Silverman *et al.*(1). When Andrews had developed the straight-wire technique in 1976, it became even more apparent that the improvement of bracket placement was the next step in the further development of fixed orthodontic appliances (2). In 1979, Thomas improved Silverman's technique by producing a customized bracket base using highly filled composites for placing brackets on stone models (3). Swetha *et al.* showed that by using the Thomas method the shear bond strengths achieved matched those of direct bonding methods (4).

Significant advantages such as shorter chair time, unimpaired view while positioning the brackets and improved patient comfort have made IDB techniques very popular (5).

Reports describing the transfer accuracy of different IDB techniques are few. Most authors compared indirect with direct bonding methods (6).

Castilla *et al*. compared five different IDB methods in their *in vitro* study. Based on photography and calipers, measurements showed silicone trays and combined methods with silicone and vacuum-formed parts to score better in terms of accuracy than vacuum trays (7). Dörfer *et al*. investigated the transfer accuracy of three different methods and also found silicone trays to produce better results than the vacuum-formed trays (8). The latest study carried out by Grünheid *et al*. examined the transfer accuracy of only one transfer method (vinyl polysiloxan trays) using an *in vivo* concept (9). They superimposed cone-beam CT scans of working models with bonded brackets of patients after IDB. The method studied showed a high transfer accuracy, but was not compared with any other method.

In the present *in vitro* study, the transfer accuracy of two different IDB methods was to be established and compared by linear and angular measurements. All measurements were carried out digitally to rule out measuring errors, which cannot be found in the present literature, except for the study of Grünheid *et al*., who examined the transfer accuracy of only one transfer method, though (9).

We tested the hypothesis of silicone trays showing higher transfer accuracy than double-vacuum forms.

Materials and methods

Fifteen silicone impressions (seven of the upper and eight of the lower jaw) taken previously for the fabrication of lingual bracket appliances were used for the study. The impressions had been taken with a two-stage double-mix technique (Bisico S1&S4, Bielefelder Dentalsilicone GmbH & Co. KG, Bielefeld, Deutschland). Each mold was cast four times so that 60 stone models (Silky-Rock Low-Expansion Die Stone ISO Type IV, Whip Mix, Dortmund, Germany) were available for the study. The four models of each impression were categorized as 'before' and 'after' for IDB technique I and 'before' and 'after' for IDB technique II.

'Before'stood for the laboratory phase of IDB, while 'after' represented the clinical bonding step in the patient's mouth.

The brackets used in this study were straight-wire twin brackets (GAC thin arch medium, Dentsply, Munich, Germany) with a 0.022" slot. After isolating the models with separating fluid (Ivoclar Separating Fluid, Vivadent, Schaan, Liechtenstein), 10 brackets were bonded to each 'before' model with a light curing adhesive (Transbond™ XT, 3M Unitek, Neuss, Germany) with due regard to the optimal position in all directions. Subsequently, the bonding material was cured in a light curing unit (Solidilite V, Shofu dental GmbH, Ratingen, Germany) for 5 minutes.

After covering the brackets with a thin layer of scan spray (Zirko Scanspray. Zirkonzahn S.R.L., Gais, Italy) to reduce reflections by the metal brackets, all 'before' models were scanned with an intraoral scanner (TRIOS® Color-P13 Shade, 3Shape Dental Systems, Copenhagen, Denmark) in high-definition mode with an accuracy of 4.5 µm (10). On the bonded models, the two transfer trays were fabricated. For all models of group I, silicone trays were made, which took place in two stages. In the first stage, the brackets and the occlusal parts of the teeth were covered with an addition curing light body silicone (Bisico S4, Bielefelder Dentalsilicone GmbH & Co. KG, Bielefeld, Germany) and left to cure for at least 150 seconds. In the second stage, the light body silicone as well as the remaining areas of the teeth was overcoated with an addition curing putty silicone (Bisico S1) (Figure 1).

For all models of group II, double-vacuum forms were prepared. First of all, the models had to be coated with a thin layer of insulating agent (Bioplast® Insulating Agent, Scheu Dental GmbH, Iserlohn, Germany), which subsequently was dispersed carefully. Then a soft 1 mm thick vacuum form (Bioplast® bleach, Scheu-Dental GmbH, Iserlohn, Germany) covering the entire brackets was made. Without removing the form, it was cut in the vestibulum with a scalpel and all areas cervically of the brackets were blocked out with wax. Over this form, a hard 0.75 mm thick vacuum form (Duran®, Scheu-Dental GmbH, Iserlohn, Germany) was prepared, which, after it was cooled down, was removed from the model and shortened with an acrylic bur as much that it only covered the occlusal and the incisal parts of the brackets. Both vacuum forms were fabricated using a pressure molding machine (Biostar®, Scheu Dental GmbH, Iserlohn, Germany) (Figure 2).

After placing the models in lukewarm water for 30 minutes to dissolve the brackets from the plaster, the transfer trays with the brackets were removed from the models and the bracket bases were grit-blasted and cleaned with 70 per cent ethanol. The brackets were then bonded to the 'after' models with a chemically curing adhesive (TransbondTM IDB, 3M Unitek, Neuss, Germany) using the respective transfer trays.

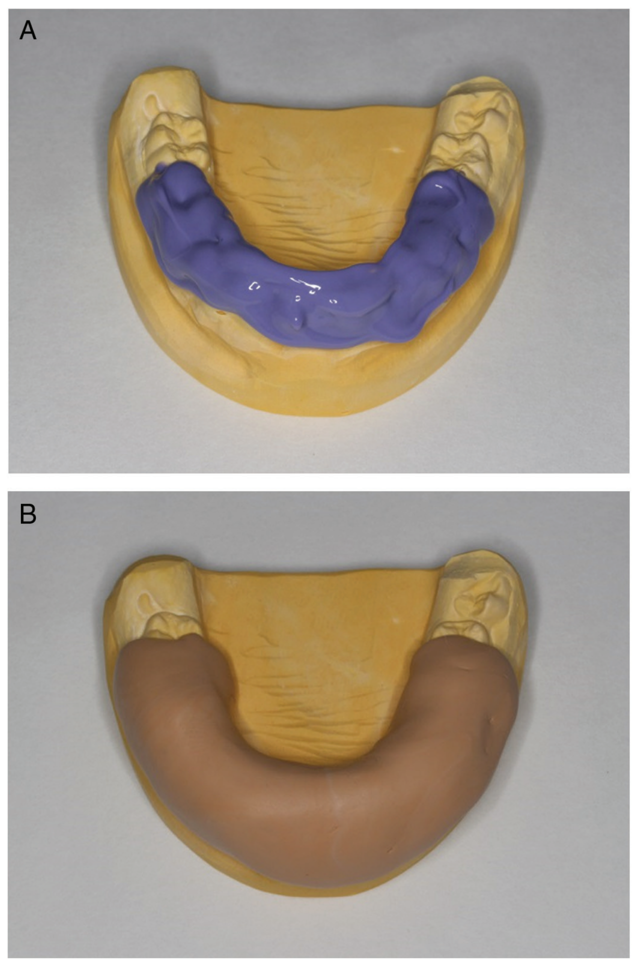

Figure 1. (A) Preparation of silicone transfer trays, light body silicone (group I). (B) Preparation of silicone transfer trays, putty silicone (group I).

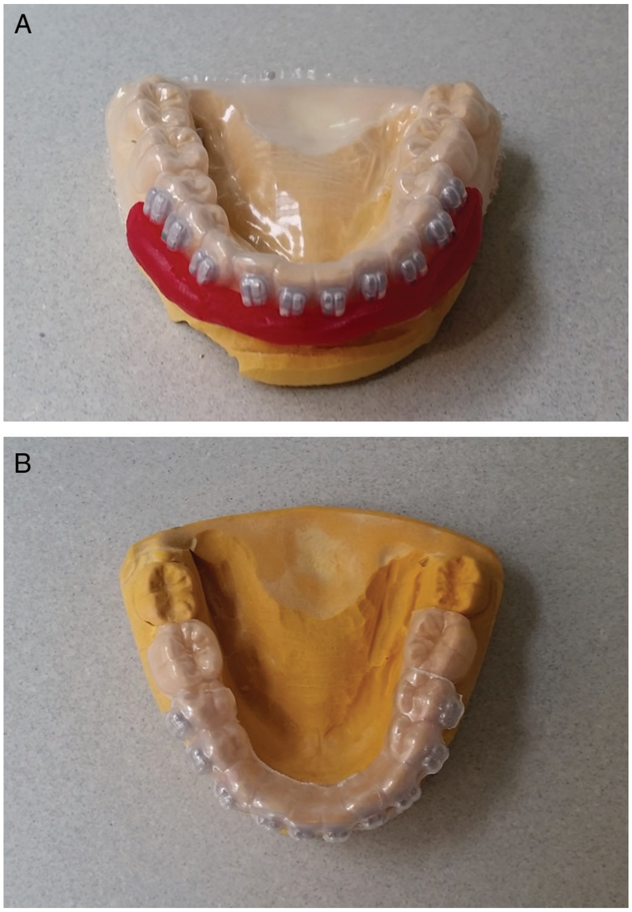

Figure 2. (A) Preparation of double-vacuum transfer trays, soft vacuum form (group II). (B) Preparation of double-vacuum transfer trays, hard vacuum form (group II).

In both study groups, the same bonding material was used to minimize the risk of a systematic error. As recommended in the manufacturer's specifications, the composite was stored in the fridge at 2–7°C and the specified mixing, dwell, and cure times were followed. All bonding procedures were performed by the same experienced orthodontist.

All 'after' models were scanned in the same manner as the 'before' models so that both models of the same mold could be superimposed using the software GOM Inspect Version 8 SR1 (GOM GmbH, Braunschweig, Germany) (Figure 3).

Therefore, the scans of the 'before' models were uploaded as 'desired elements', whereas the 'after' models were uploaded as 'actual elements'. Millimeters (mm) were set as the standard unit of both model types.

Subsequently an initial overlay was executed, which displayed that the deviations in the posterior areas of the dental arches were higher. Despite the high resolution of the scanner, it had problems to reflect the extent of the whole dental arch accurately. This difficulty was already described in 2015 by Anh *et al.* (11). To avoid these issues, measurements were carried out tooth by tooth. The tooth of interest was selected, the bracket was deselected, and a 'local best-fit' was made. Afterwards the bracket was selected again and the discrepancies between the 'before' and 'after' positions of the brackets were measured. Twelve measuring points per bracket were defined to calculate differences in the occluso-cervical (vertical), mesio-distal (horizontal), and bucco-lingual (transversal) directions as well as in tip, rotation, and torque (Table 1; Figure 4). Positive values indicated

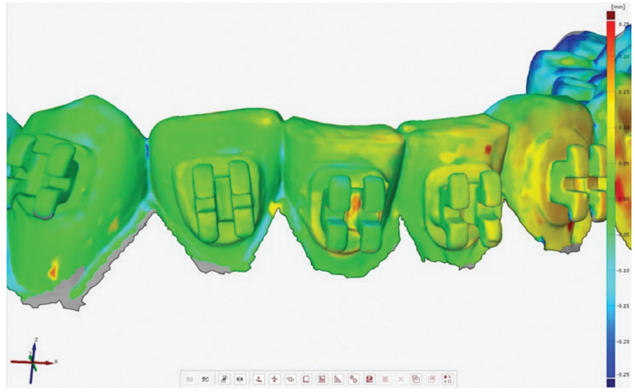

Figure 3. Superimposition of the 'before' and 'after' positions for a patient.

Table 1. Definitions of the 12 measuring points.

Point 1	Mesio-occlusal bracket wing, occlusal edge
Point 2	Mesio-occlusal bracket wing, cervical edge
Point 3	Disto-occlusal bracket wing, occlusal edge
Point 4	Disto-occlusal bracket wing, cervical edge
Point 5	Mesio-occlusal bracket wing, mesial edge
Point 6	Disto-occlusal bracket wing, distal edge
Point 7	Mesio-cervical bracket wing, mesiale edge
Point 8	Disto-cervical bracket wing, distale edge
Point 9	Mesio-occlusal bracket wing, buccal plane
Point 10	Disto-occlusal bracket wing, buccal plane
Point 11	Mesio-cervical bracket wing, buccal plane
Point 12	Disto-cervical bracket wing, buccal plane

that the 'after' models were more exposed at this measuring point, whereas negative values indicated a more exposed area of the 'before' models. For example, a value of +0.17 mm at point 1 and 3 indicates a shift of the 'after' position of the bracket in the occlusal direction (Figure 5).

Statistical analysis

To calculate the transfer error of the methods examined, means and standard deviations of the divergence between the 'before-' and 'after'-positions were calculated. For each transfer method (I and II), non-normally distributed data were evaluated with the non-parametric Kruskall–Wallis analysis to test for an overall significant difference of transfer errors among the three tooth groups (incisors, canines, premolars), followed by multiple pairwise comparisons with Dunn–Bonferroni *post hoc* tests. The two transfer methods were compared with the Mann–Whitney *U* test, because the data were not distributed normally. A *P*-value of less than 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 22.

The sample size was determined based on previous literature (9). With an observed sample size of $n = 132$ and $n = 134$, respectively, a power analysis for Mann–Whitney *U* tests (two-tailed) conducted *a posteriori* using G*Power 3.1.9.2 indicated 89 per cent power to detect a small effect size (Cohen's $d = 0.4$) at a significance level of 0.05.

Results

Eighteen brackets of method I (silicone trays) and 16 brackets of method II (double-vacuum forms) were lost during the transfer to the

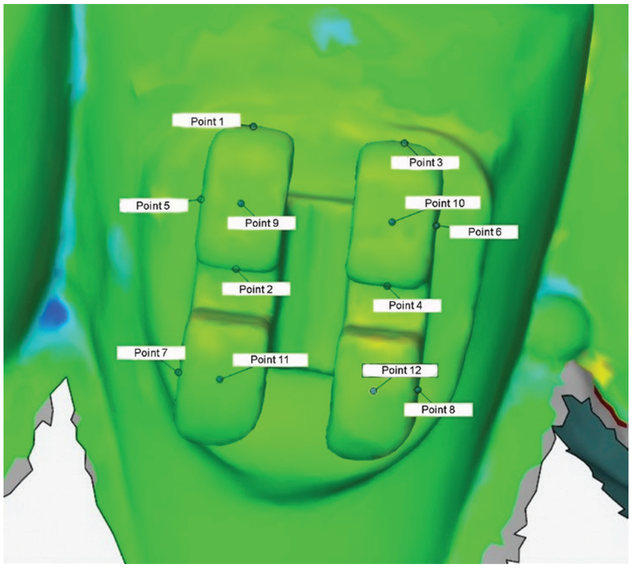

Figure 4. The 12 measuring points.

'after'-models and were not included in the evaluation. Altogether the transfer accuracy of 266 brackets was examined—132 of method I and 134 of method II.

With both methods, the biggest error in the linear variables occurred in the vertical dimension followed by the transversal and the horizontal dimensions. Method I showed the highest angulatory deviation in tip followed by torque and rotation. With method II, torque showed the biggest error followed by tip and rotation (Tables 2 and 3).

In all dimensions, linear and angulatory, transfer errors were more pronounced with method II.

Assessment of clinical acceptability was based on the Americon Board of Orthodontics (ABO) objective grading system for dental casts. The authors defined deviations from proper alignment of ≤0.5 mm as clinically acceptable. In the case of an average-sized molar, a marginal ridge discrepancy of 0.5 mm would lead to a crown tip deviation of 2 degrees, which is why angulatory deviations of ≤2 degrees are considered to be clinically acceptable (12). To also take into account of the possibility that two adjacent brackets are deviated in opposite directions, the limit of clinical acceptability in the present study was set at 0.25 mm and 1 degree, respectively.

Tables 4 and 5 show the prevalences of transfer errors within the clinically acceptable range. One hundred per cent of the horizontal and transversal errors of both methods were within the range. With method I, 98.5 per cent of the vertical, 93.9 per cent of tip, 99.2 per cent of rotation, and 94.7 per cent of torque deviations were within the range. With method II, 94 per cent of the vertical, 80.6 per cent of tip, 90.3 per cent of rotation, and 83.6 per cent of torque deviations were within the range.

Tables 2 and 3 show the significance levels of differences between different tooth types for method I and II. With method I, a significant difference was detected in the horizontal dimension, whereas method II only showed no differences. For all significant groups, *post hoc* tests were performed to analyse the differences in detail. A comparison of the two methods brought to light significant differences in the vertical and horizontal directions, as well as for tip, rotation, and torque, all in favour of method I (Table 6).

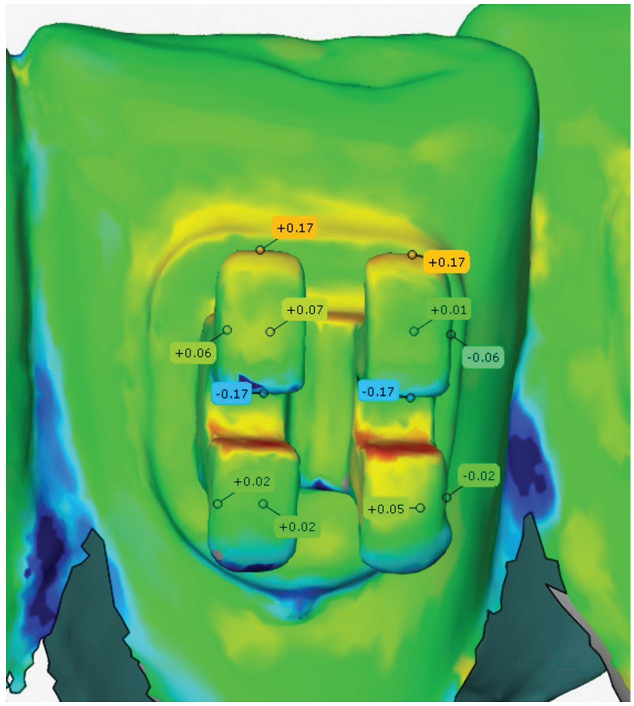

Figure 5. Example of a bracket with discrepancies at the 12 measuring points.

Discussion

This *in vitro* study was designed to establish the three-dimensional transfer accuracy of two indirect bracket bonding methods by comparing silicone trays and double-vacuum forms. This is of clinical relevance, because both methods are common IDB procedures used by many orthodontists in their everyday practice and have never been compared digitally.

Altogether 300 brackets were bonded. Of these, 34 were not eligible for measurements for various reasons (mistakes during the IDB procedure, debonding during the removal of the scan spray, incomplete capture by the scanner). This left 266 brackets with 12 measuring points each for evaluation. A failure rate of almost 12 per cent clearly appears high, but has to be relativized by the fact, that most of the losses happened during the removal of the scan spray and only three brackets got lost during the IDB procedure (two in the silicone group and one in the double-vacuum group). Thus, the clinically relevant failure rate was only 1.3 and 0.7 per cent, respectively.

Comparable literature is available: Castilla *et al.* (7) and Dörfer *et al.* (8) carried out *in vitro* studies with stone models representing the baseline and clinical models, but measurements were only made with digital photography and calipers. Grünheid *et al.* (9) carried out an *in vivo* study examining cone beam CTs of the baseline models and the patients after bonding the brackets and measuring them digitally. However, they only evaluated one transfer method (vinyl polysiloxan).

For the fabrication of the stone models used in our study, 15 addition curing silicone impressions were cast four times each with super hard stone according to the manufacturer's specifications with reset times of at least 24 hours between the casting processes. Nevertheless, some minor deformation of the impressions may occur during repeated casting and introduce an unquantifiable error in the models. As A-silicones have a resilience of 99.8 per cent, this error and the resulting inaccuracies in the measurements may be deemed

Table 2. Means and standard deviations of transfer errors with method I. *P*-values calculated by the Kruskall–Wallis test indicate an overall difference between the three tooth groups with respect to the horizontal direction, rotation, and torque. *P*-values from Dunn–Bonferroni *post hoc* tests show the significant differences between the pairs of tooth groups where an overall significant difference was found.

Variables (Transfer errors)	Mean ± SD Incisors (I) N = 54	Canines (C) N = 24	Premolars (P) N = 54	All Groups N = 132	Overall difference between tooth groups (*P*-values)	*Post hoc* comparisons (*P*-values)
Vertical (mm)	0.063 ± 0.040	0.076 ± 0.066	0.077 ± 0.056	0.071 ± 0.052	$P = 0.725$	—
Horizontal (mm)	0.021 ± 0.016	0.024 ± 0.016	0.040 ± 0.026	0.029 ± 0.022	$P < 0.001$	I/P: $P < 0.001$*
Transversal (mm)	0.040 ± 0.021	0.040 ± 0.036	0.052 ± 0.037	0.045 ± 0.031	$P = 0.146$	—
Tip (°)	0.345 ± 0.474	0.225 ± 0.199	0.568 ± 1.280	0.414 ± 0.882	$P = 0.045$	C/P: $P = 0.066$
Rotation (°)	0.299 ± 0.258	0.237 ± 0.166	0.344 ± 0.230	0.306 ± 0.234	$P = 0.082$	—
Torque (°)	0.331 ± 0.291	0.456 ± 0.298	0.401 ± 0.286	0.382 ± 0.292	$P = 0.114$	—

Table 3. Means and standard deviations of transfer errors with method II. *P*-values calculated by the Kruskall–Wallis test indicate no overall difference between the three tooth groups.

Variables (Transfer errors)	Mean ± SD Incisors (I) N = 52	Canines (C) N = 29	Premolars (P) N = 53	All Groups N = 134	Overall difference between tooth groups (*P*-values)	*Post hoc* comparisons (*P*-values)
Vertical (mm)	0.113 ± 0.073	0.094 ± 0.088	0.102 ± 0.077	0.105 ± 0.078	$P = 0.253$	—
Horizontal (mm)	0.046 ± 0.040	0.054 ± 0.042	0.043 ± 0.036	0.046 ± 0.039	$P = 0.426$	—
Transversal (mm)	0.046 ± 0.033	0.054 ± 0.040	0.046 ± 0.034	0.048 ± 0.035	$P = 0.600$	—
Tip (°)	0.525 ± 0.455	0.867 ± 1.321	0.647 ± 0.522	0.647 ± 0.755	$P = 0.414$	—
Rotation (°)	0.499 ± 0.396	0.338 ± 0.275	0.431 ± 0.496	0.438 ± 0.420	$P = 0.199$	—
Torque (°)	0.641 ± 0.534	0.590 ± 0.559	0.825 ± 1.288	0.703 ± 0.913	$P = 0.745$	—

Table 4. Prevalence of clinically acceptable transfer errors with method I.

	Number of bonded teeth	Vertical (%)	Horizontal (%)	Transversal (%)	Tip (%)	Rotation (%)	Torque (%)
Incisors (I)	54	100	100	100	90.7	98.1	94.4
Canines (C)	24	95.8	100	100	100	100	91.7
Premolars (P)	54	98.1	100	100	94.4	100	96.3
Total	132	98.5	100	100	93.9	99.2	94.7

Table 5. Prevalence of clinically acceptable transfer errors with method II.

	Number of bonded teeth	Vertical (%)	Horizontal (%)	Transversal (%)	Tip (%)	Rotation (%)	Torque (%)
Incisors (I)	52	94.2	100	100	84.6	86.5	84.6
Canines (C)	29	89.7	100	100	72.4	96.6	86.2
Premolars (P)	53	96.2	100	100	81.1	90.6	81.1
Gesamt	134	94.0	100	100	80.6	90.3	83.6

to be negligible (13). Only air bubbles in the stone could lead to discrepancies in the digital superimposition of the models or an impaired fit accuracy of the transfer trays.

The brackets used in this study were conventional GAC thin-arch medium brackets with a 0.022″ slot. Because they may differ from other bracket systems in design and dimension, the results of this study should not be unconditionally extrapolated to other systems.

For scanning the models, an intraoral scanner was used. In a recent study which compared six currently available intraoral scanners, the Trios scanner used in the present study showed the highest precision (4.5 ± 0.9 µm) and trueness (6.9 ± 0.9 µm) (14). Model scanners were unsuited for our purposes, because they would not have sufficiently well captured undercuts. Nevertheless, spraying the brackets with a thin layer of scan spray proved to be necessary to avoid reflections of the stripe light by the metal surface. Although spraying the brackets was done by an experienced dentist (this significantly improves the homogeneity of layer thickness), a resultant unquantifiable systematic error cannot altogether be excluded (15).

The 3D inspection and mesh processing software GOM Inspect Version 8 presents data with an accuracy of up to 1 µm. It also generates a local best-fit so that the teeth can be measured seperately. This was necessary to avoid scanning-related errors attributable to

Table 6. Significance of differences between the two methods.

Variables (Transfer errors)	Mean ± SD Method I (silicone trays) *N* = 132	Mean ± SD Method II (double-vacuum forms) *N* = 134	*P*-values
Vertical (mm)	0.071 ± 0.052	0.105 ± 0.078	$P < 0.001$
Horizontal (mm)	0.029 ± 0.022	0.046 ± 0.039	$P = 0.001$
Transversal (mm)	0.045 ± 0.031	0.048 ± 0.035	$P = 0.716$
Tip (°)	0.414 ± 0.882	0.647 ± 0.755	$P < 0.001$
Rotation (°)	0.306 ± 0.234	0.438 ± 0.420	$P = 0.048$
Torque (°)	0.382 ± 0.292	0.703 ± 0.913	$P < 0.001$

discrepancies in arch width (11). For the measuring points, 12 predefined positions were chosen. Inaccuracies occurring while marking the points cannot altogether be ruled out. Therefore, means of four measuring points for linear deviations and means of two angles for angulatory deviations were used for statistical analysis.

The superimposition of the 'before' and 'after' models was intended to demonstrate the linear and angulatory transfer accuracy of two indirect bracket bonding methods. It was also expected to show tendencies of specific tooth groups (incisors, canines, premolars) to deviate in a particular direction.

Both methods showed the most pronounced linear deviation in the vertical direction with a clear error in the occlusal direction, but with significantly higher misfits in group II (double-vacuum forms). Castilla *et al*. (7) and Dörfer *et al*. (8) reported similar results. This deviation might have been due to an irregular occlusal pressure on the trays during the curing process or simply to the tendency of trays to take the easiest way, i.e. toward occlusal, if they do not fit perfectly.

In the transversal direction, both methods showed similar transfer errors to the vestibular side. This might have been due to an excess of composite material spreading the distance between the bracket base and the model. Predominantly occlusal pressure during the curing process could have been another factor with resultant gingival deviation of the transfer trays. The clear tendency of torque towards oral supports this assumption. The *in vivo* study of Grünheid *et al*. (9) showed similar results.

To also take account of the possibility that two adjacent brackets are deviated in opposite directions, the limit of clinical acceptability in the present study was set at 0.25 mm and 1 degree, respectively (12). In the horizontal and transversal dimensions, all deviations of both methods were within these limits. In the vertical and angulatory dimensions, some values lay outside these limits, more often in group II (double-vacuum forms). Grünheid *et al*. (9) reported similar results, but with higher readings, although they set the clinical acceptability at 0.5 mm and 2 degrees, respectively. Castilla *et al*. (7) defined a limit of ≤0.25 mm as clinically acceptable for deviations in linear dimensions.

A comparison by tooth shapes showed that with method I most inaccuracies were found in the premolar region for all directions but torque. For method II, no such pattern was seen. Albeit limited to a single IDB method using vinyl polysiloxan trays, the *in vivo* study by Grünheid *et al*. (9) showed a very similar tendency, although the authors attributed it to the poor accessibility of the posterior areas of the mouth. Significant differences ($P < 0.05$) between tooth shapes within one method were seen in the horizontal and transversal directions, for rotation with method I and in the horizontal direction with method II.

Like in the studies of Castilla *et al*. (7) and Dörfer *et al*. (8), the present study detected more inaccuracies by bonding with double-vacuum forms than with silicone trays. Significant differences between the methods were found in the vertical and horizontal dimensions as well as for torque.

Valuing the results of the present study, one should keep in mind that it was an *in vitro* study, which implies that the error may be higher in an *in vivo* setting, due to additional factors like initial bracket positioning error or limited accessibility in the mouth with more difficult transfer. As the experimental setup of the present study would also be suitable for humans, it should be used *in vivo* in order to better assess the clinical relevance.

Conclusion

To improve transfer accuracy of IDB in orthodontics, silicone trays should be given preference, because they showed higher precision in all measured dimensions. However, the differences between the methods were significant for only half of the investigated parameters.

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Conflict of Interest Statement

None to declare.

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