Original Article

Indirect bonding: an in-vitro comparison of a Polyjet printed versus a conventional silicone transfer tray

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ABSTRACT

Objectives: To investigate and compare transfer accuracy between a Polyjet printed indirect bonding (IDB) tray (SureSmile, Dentsply Sirona, Richardson, TX, USA) and a conventional two-layered silicone tray.

Materials and Methods: Plaster models of 24 patients were digitized with an intraoral scanner, and brackets and tubes were positioned virtually on the provider's homepage. IDB trays were designed over the planned attachments and Polyjet 3D-printed. For the conventional tray, brackets and tubes were bonded in their ideal positions manually before fabricating a two-layered silicone tray. For both trays, attachments were transferred indirectly to corresponding models. A second scan was performed of each bonded model to capture actual attachment positions, which were then compared to initial bracket positions using Geomagic Control (3D Systems Inc., Rock Hill, SC, USA). Linear and angular deviations were evaluated for each attachment within a clinically acceptable range of $\leq$0.2 mm and 1°. A descriptive statistical analysis and a mixed model were executed.

Results: Both trays showed highest accuracy in the orobuccal direction (99.5% for the 3D-printed tray and 100% for the conventional tray). For the 3D-printed tray, most frequent deviations were found for torque (15.4%) and, for the silicone tray, for rotation (1.9%). A significant difference was observed for angular measurements ($P = .004$) between the trays.

Conclusions: Transfer accuracy of Polyjet printed IDB tray is not as high as transfer accuracy of the conventional silicone tray, though both trays show good results and are suitable for clinical application. (*Angle Orthod.* 2022;92:728–737.)

KEY WORDS: Indirect bonding; Transfer accuracy; CAD/CAM; 3D printing; Polyjet printing technology; Digital orthodontics

INTRODUCTION

The Andrews straight wire technique requires ideal bracket and tube positioning to avoid undesired tooth movements.[1] Indirect bonding (IDB) is a procedure offering a comfortable and more accurate placement of brackets and tubes.[2,3] Initially, the intraoral surfaces of a patient need to be captured either by taking an impression or an intraoral scan, which then serves as a

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Accepted: May 2022. Submitted: December 2021.
Published Online: July 14, 2022
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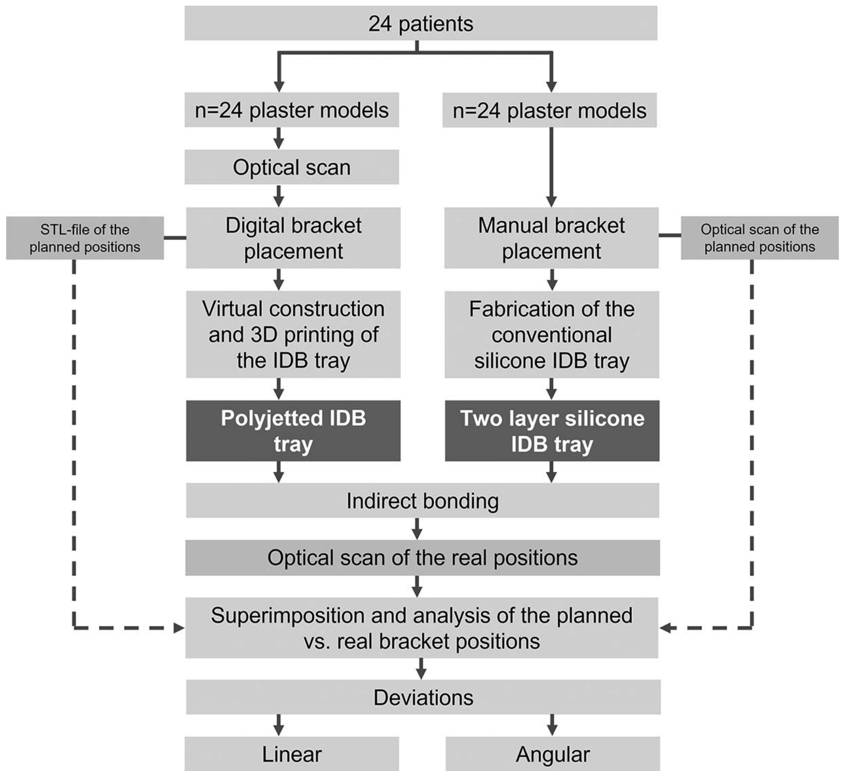

Figure 1. Method chart for investigated IDB trays.

basis for positioning brackets and tubes either conventionally or digitally. Next, a transfer tray is manufactured over the brackets, allowing the orthodontist to transfer all included brackets simultaneously into the patient's mouth. Advantages of this technique are shorter clinical chair time, unimpaired bracket placement in posterior regions, improved patient comfort, and the possibility to delegate parts of the bonding procedure.[3,4] However, Czolgosz et al.[5] described disadvantages for IDB such as a longer workflow caused by an additional appointment and extra laboratory work along with higher costs for materials and salary for the technician. Previous studies on the transfer accuracy of IDB mostly investigated polysiloxane trays and showed good overall clinical results,[6–9] albeit differences in tray design.[10] Recently, computer-aided design/computer-aided manufacturing (CAD/CAM)-based technologies and the increasing application of rapid prototyping in orthodontics provide new options for tray design and material selection in a digital workflow.[11–15] Studies on the transfer accuracy of CAD/CAM-based and 3D-printed IDB trays show at least equally good results as conventional IDB trays and assume fewer laboratory errors and good reproducibility.[11–13] In these studies, mostly Stereolithography (SLA) or Digital Light Processing (DLP) printing technology were used to build the IDB trays. Comparing available printing technologies in the field of orthodontics, Polyjet printing is the most accurate method in additive manufacturing.[16–20] So far, it was not applied to IDB. The aim of this study was to analyze the transfer accuracy of a 3D-printed IDB tray (SureSmile, Dentsply Sirona, Richardson, TX, USA) which was fabricated using Polyjet 3D printing technology and to compare it to a conventional two-layered silicone IDB tray (Figure 1).

MATERIALS AND METHODS

A sample size calculation was conducted (power: 80%; $\alpha = 2.5\%$; medium size effect [Cohen's $d = 0.667$]) for a paired *t*-test and determined a minimum of 24 patients was required. No ethical approval was needed to conduct this study.

3D-Printed Tray

Plaster models of 24 patients with full permanent dentition including the second molars and different malocclusions were digitized using a TRIOS 3W (3Shape, Copenhagen, Denmark) optical scanner and exported as STL-files. For each patient, a new case file was created on the SureSmile Advanced treatment simulation and planning homepage to which STL-files were uploaded. Digital diagnostic models were received to simulate the attachment placement. For this, a bracket or tube (discovery smart/pearl,

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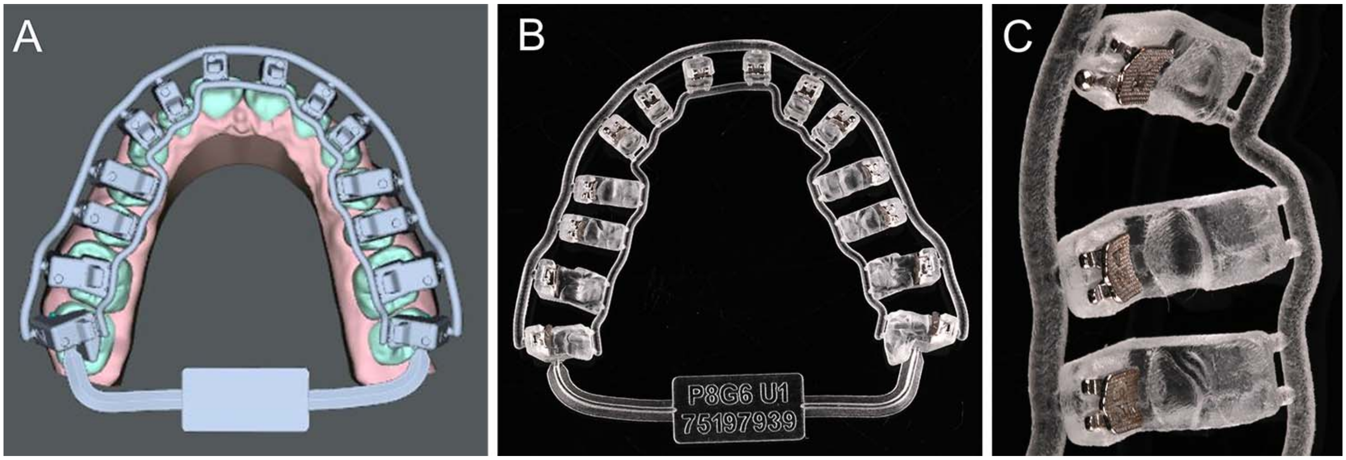

Figure 2. 3D-printed IDB tray: (A) simulation on the SureSmile Advanced Homepage, (B) actual unsegmented indirect bonding tray, (C) side view.

Ortho-Cast M-Series [0.018 inch; Roth prescription], Dentaurum, Ispringen, Germany) was chosen from a bracket library for each tooth, and all virtual attachments were placed on the buccal surfaces using FA-point as a reference and, if needed, individually adjusted. Subsequently, an IDB tray was virtually designed over each dental arch based on the set attachment positions. The design included transfer caps for each tooth, which laid upon the occlusal relief and held the attachments in place on the buccal surface by retentively filling out the bracket slot and additionally holding it in a mesiodistal direction and from the occlusal side. The transfer caps were connected to the adjacent teeth by a buccal and an oral connector including intended breaking points (Figures 2 and 3). Finally, all IDB trays were ordered and 3D-printed by SureSmile using an Objet Eden500V 3D Polyjet printer (Stratasys, Eden Prairie, MN, USA). For later comparison, STL-files of the dental arches and their virtually planned bracket and tube positions were exported from the homepage.

Conventional Silicone Tray

Plaster models of the same set of patients were isolated (separating medium 162-800-00, Dentaurum) and bonded with the same brackets and tubes in their intended positions on the buccal surface. Subsequently, an intraoral scan was performed to capture the ideal

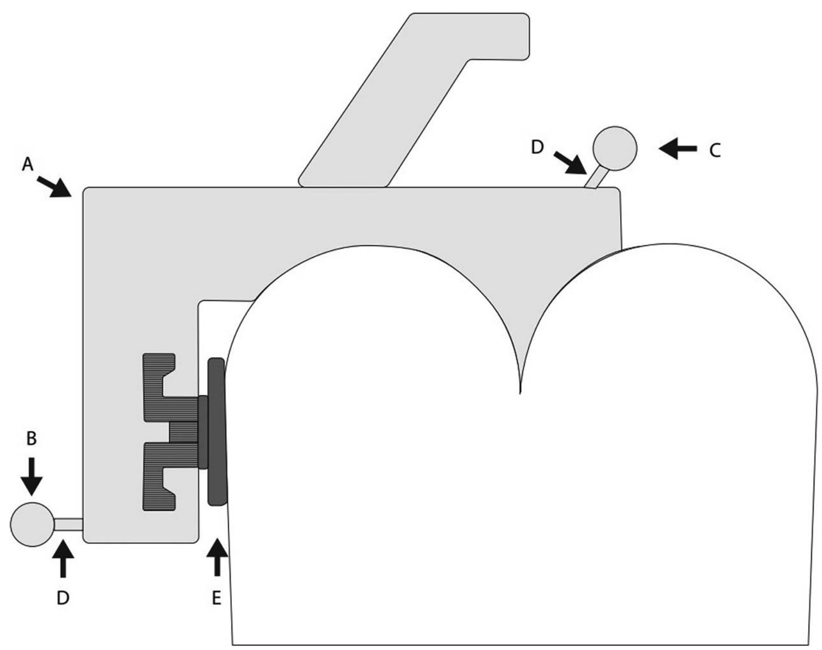

Figure 3. Profile scheme of the 3D-printed tray: (A) transfer cap, (B) buccal connecting link, (C) oral connecting link, (D) intended breaking points, (E) bracket base.

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Figure 4. Conventional two-layered silicone IDB tray.

bracket positions in a STL-file. The conventional IDB tray was fabricated according to Nedwed et al.[21] (Figure 4). For this, Memosil 2 (Kulzer, Hanau, Germany) was extruded in one line on the buccal surface of the teeth fully covering all attachments. Then, Futar D (Kettenbach, Eschenburg, Germany) was applied on top of the Memosil line as occlusal support. Both materials were smoothed manually and all gingival bracket wings and hooks were cut free using a scalpel. Finally, a vertical incision was made in the center of each attachment to avoid debonding later during tray removal. Then, the plaster models with the silicone tray were placed in water for 10 minutes to separate the tray and its brackets from the model.

In-Vitro Bracket Transfer

After receiving the 3D-printed IDB trays, all attachments were placed into the respective transfer caps. For the silicone trays, the brackets and tubes were already integrated so no manual placement was needed. All attachment bases were cleaned with acetone and coated with Transbond XT (3M Unitek Deutschland, Neuss, Germany). To prevent early polymerization, the trays were put in a black storage box. To simulate the indirect bonding procedure, another set of plaster models was fabricated. Then, isopropanol was used to clean the teeth of the plaster models and Transbond XT Primer (3M Unitek Deutschland) was applied to the expected positions on the buccal surface. Then, all brackets and tubes were transferred using the 3D-printed and the silicone tray, respectively. Composite residue was removed with a dental probe and the composite-filled gap between the attachment and the tooth surface of the plaster model was light cured in high power mode at 1400 mW/cm^2 (VALO LED, Ultradent Products, South Jordan, UT,

Figure 5. Clinical workflow of the 3D-printed tray: (A) cleaned surface with applied Transbond XT Primer, (B) transfer process, (C) and (D) removal of the tray, (E) transferred brackets.

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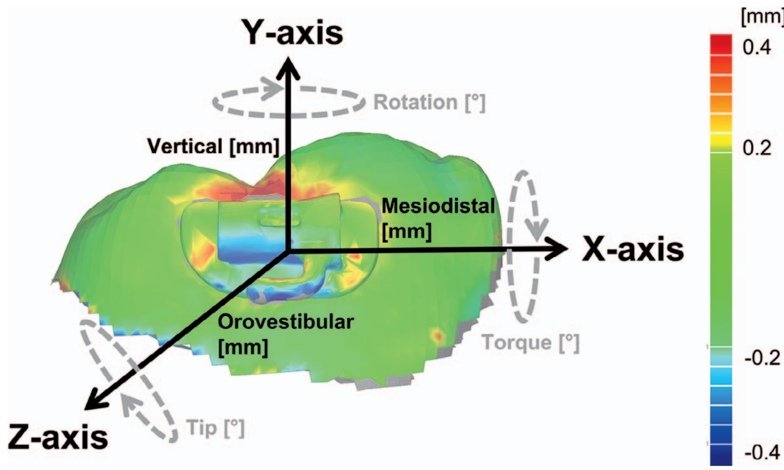

Figure 6. Superimposition of the planned and the actual bracket position on the surface of a molar. The spectrum of deviations is color coded as contrast to the ideal green bracket position.

USA) for 10 seconds from all accessible directions while holding the IDB tray in place with finger pressure. Removal of the 3D-printed IDB tray was executed by breaking the oral connectors at the intended breaking points using a dental scaler and carefully pulling the tray off to the buccal, cap by cap. The silicone tray was removed in total by lifting the elastic silicone wings adjacent to the vertical incision for every attachment and pulling it over every bracket wing and tube with a scaler. After removal, each attachment was light cured again for 10 seconds from the occlusal surface (Figure 5). Finally, the actual bracket and tube positions were captured for both trays with another intraoral scan using scanning powder (METAL-POWDER Dry Blue, R-dental Dentalerzeugnisse, Hamburg, Germany) applied to the reflecting metal surfaces of the brackets in advance.

Superimposition

The STL-files from the test and reference models were imported to Geomagic Control (3D Systems, Rock Hill, SC, USA) to calculate the deviations of the planned and the actual bracket and tube positions for each IDB tray and patient. For this, the corresponding tooth surfaces from the test and reference models were superimposed using a scripted local best-fit alignment as previously described by Koch et al.[22] The attachment deviations were described in three linear (mesiodistal, vertical, orobuccal) and three angular (torque, rotation, tip) directions (Figure 6).

Statistical Analysis

Statistical analysis was executed with SPSS (Version 27.0, IBM, Armonk, NY, USA), calculating means and standard deviations for each tooth group (incisors, canines, premolars, molars) and each tray type. Linear deviations of $\leq$0.2 mm and angular differences of $\leq$1° were defined as clinically acceptable according to the set limitations by the American Board of Orthodontics[23] and others.[7,24] A mixed-model analysis was performed to compare the transfer accuracy of both IDB trays.

RESULTS

Tables 1 and 2 show the transfer accuracies of the 3D-printed and the conventional silicone trays as means and standard deviations. For the 3D-printed IDB tray, the most accurate bracket placements for linear measurements were found in the orobuccal direction (99.5% within the set limits) and for angular measurements for tip (93.3%) (Figure 7). The most frequent deviations were found in the vertical direction (5.2%) and for torque (15.4%), with the highest deviations in the vertical direction of 0.10 $\pm$ 0.08 mm and for torque of 0.78 $\pm$ 0.60°. For the Polyjet printed IDB tray in general, placement of incisor brackets showed a higher transfer accuracy than molar tubes.

Table 1. Means and Standard Deviations of Transfer Errors With 3D-Printed IDB Tray (Absolute Values)

Tooth Type	n*	Mesiodistal (mm)	Vertical (mm)	Orobuccal (mm)	Torque (°)	Rotation (°)	Tip (°)
Incisors	188	0.04 ± 0.04	0.06 ± 0.04	0.02 ± 0.01	0.38 ± 0.29	0.49 ± 0.46	0.45 ± 0.50
Canines	96	0.06 ± 0.07	0.07 ± 0.06	0.02 ± 0.02	0.47 ± 0.40	0.65 ± 0.81	0.52 ± 0.45
Premolars	189	0.06 ± 0.05	0.07 ± 0.06	0.02 ± 0.05	0.60 ± 0.53	0.56 ± 0.52	0.48 ± 0.41
Molars	182	0.06 ± 0.05	0.10 ± 0.08	0.02 ± 0.03	0.78 ± 0.60	0.50 ± 0.48	0.25 ± 0.33

* n indicates number of brackets used for analysis.

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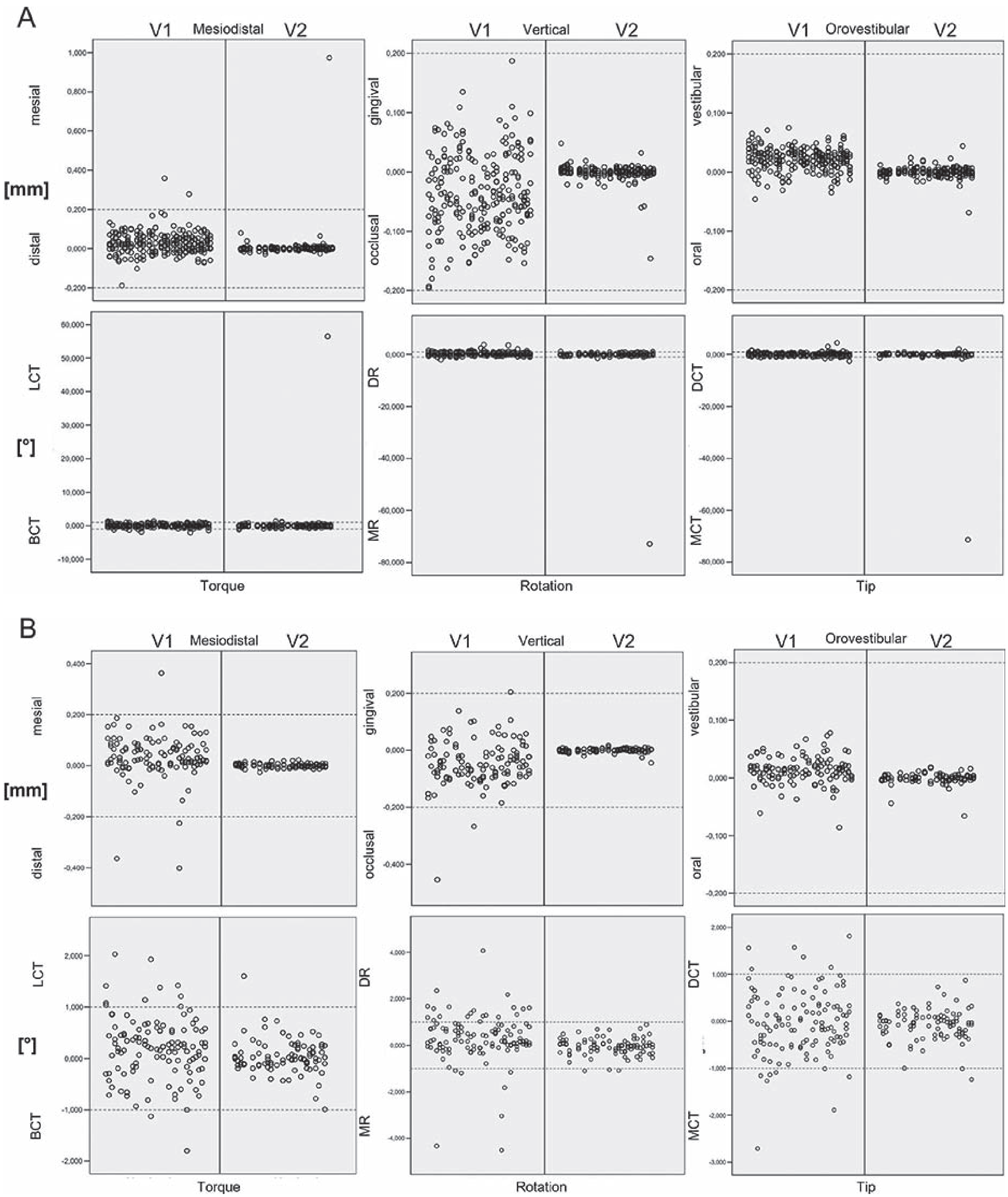

Figure 7. Scatter plots of deviations (absolute values) for each bracket and each direction for both investigated trays (V1 = 3D-printed IDB tray, V2 = conventional silicone IDB tray). Lines mark the clinically acceptable range. (A) incisors, (B) canines, (C) premolars, (D) molars. BCT indicates buccal crown torque; DCT, distal crown tip; DR, distorotation; LCT, lingual crown torque; MCT, mesial crown tip; MR, mesiorotation.

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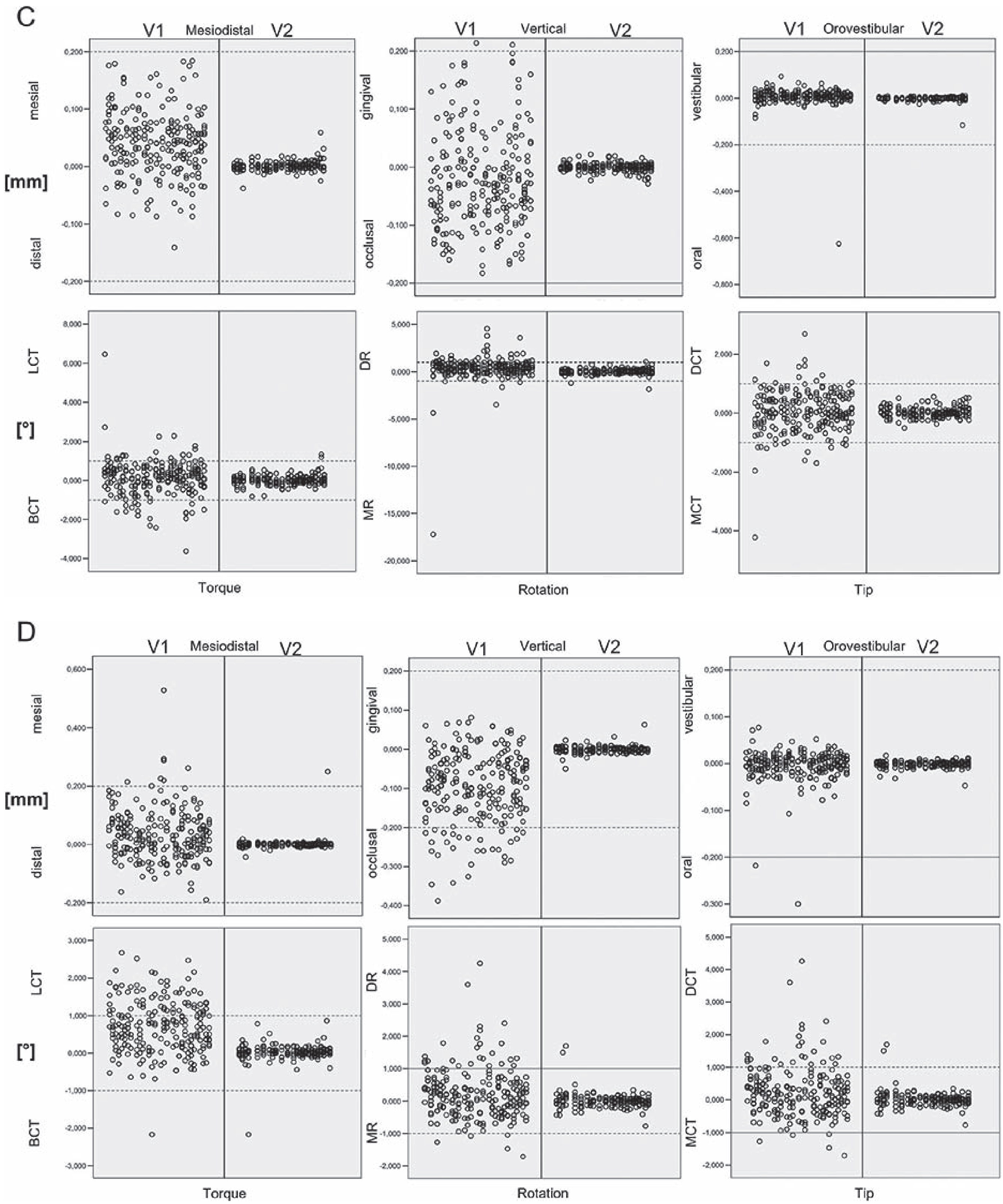

Figure 7. Continued.

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Table 2. Means and Standard Deviations of Transfer Errors With Conventional Silicone IDB Tray (Absolute Values)

Tooth Type	n*	Mesiodistal (mm)	Vertical (mm)	Orobuccal (mm)	Torque (°)	Rotation (°)	Tip (°)
Incisors	185	0.01 ± 0.07	0.006 ± 0.13	0.005 ± 0.007	0.53 ± 4.14	0.67 ± 5.35	0.58 ± 5.23
Canines	93	0.006 ± 0.006	0.005 ± 0.006	0.006 ± 0.009	0.21 ± 0.25	0.26 ± 0.25	0.23 ± 0.24
Premolars	181	0.005 ± 0.007	0.005 ± 0.005	0.004 ± 0.01	0.17 ± 0.19	0.17 ± 0.22	0.13 ± 0.13
Molars	174	0.006 ± 0.02	0.005 ± 0.007	0.004 ± 0.005	0.11 ± 0.20	0.13 ± 0.19	0.14 ± 0.16

* n indicates number of brackets used for analysis.

For the conventional silicone IDB tray, the best results for linear measurements were found in the orobuccal and vertical direction (100% within the set limits) and, for angular measurements, for torque (98.7%). The most frequent transfer errors occurred in the mesiodistal direction (0.3%) and for rotation (1.9%), with the highest deviations of 0.01 ± 0.07 mm in the mesiodistal direction and 0.67 ± 5.35° for rotation. Incisors and canines were most frequently affected by transfer errors. A possible bias for each direction was investigated for both IDB trays and is shown in Tables 3 and 4. A significant difference was observed for all angular measurements ($P = .004$) between the two trays, but not for linear measurements ($P = .57$) (Table 5). In the mixed-model calculation, no significance was found for the interactions between trays and tooth groups.

DISCUSSION

Of all 672 attachments, 655 were successfully transferred using the 3D-printed IDB tray and 633 using the conventional silicone tray. This difference was due to bracket debonding during tray removal. Similar to the findings of Dörfer et al.[6] and Schmid et al.[7], and taking into account the differences in tray material, design and fabrication method, the most frequent linear deviations for the 3D-printed IDB tray were found in the vertical dimension toward the occlusal. Inaccuracies in the vertical dimension seem to be a common problem in additive manufacturing.[16,17,19] The 3D-printed IDB tray investigated was manufactured using Polyjet 3D printing technology, which allows the fabrication of objects consisting of multiple materials in a single process and is comparable to conventional ink printing. Printer heads jet photosensitive polymer resin droplets onto a build platform and cure them by immediate application of UV light, layer by layer, until an object is built. Tee et al.[25] found that Polyjet printed objects with feature sizes below 500 μm do not reach the designated vertical dimension. In the current study, the 3D-printed IDB tray showed very filigreed areas, especially the transfer caps that hold the attachments in place. The smaller these structures got toward the tips that filled the bracket slots, the more they were prone to imprecisions due to rounded and undersized surface edges, which can cause deviations, especially in the vertical dimension and in torque. Another potential source of error can occur during post-processing, when the gel-like resin, which is used as support material, is washed off. If this process is not done strictly according to the manufacturer's instructions and invisible remains of resin stay on the surface, they represent an uneven surplus on the tray and can be responsible for further deviations depending on their localization. The two-layered silicone tray investigated in the current study reached 100% clinical acceptance for the vertical and the orobuccal dimension. Consequently, the application of two different silicones differing in their elastic properties seemed more accurate than the use of one single-tray material. As an A-silicone and with a Shore-A-Hardness of 72, Memosil 2 is holding the attachments in their intended position and at the same time allowed an easy removal and low debonding rate when an additional vertical incision was added. On the other hand, Futar D as an A-silicone with a Shore-D-Hardness of 42, enabled stability in all dimensions and guidance during the bracket transfer.[21] Indeed, the most frequent deviations using the silicone tray were

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Table 3. Prevalence of Bracket Transfer Errors and Their Directional Bias With 3D-Printed IDB Tray (in %)[a]

	Dimensions											
	Mesiodistal (%)		Vertical (%)		Orobuccal (%)		Torque (%)		Rotation (%)		Tip (%)	
Tooth Type	Distal	Mesial	Occlusal	Gingival	Oral	Buccal	BCT	LCT	MR	DR	MCT	DCT
Incisors	0	0.5	0	0	0	0	2.1	2.1	1.6	7.4	2.7	4.3
Canines	3.1	0	2.1	1.0	0	0	2.1	6.3	6.3	15.6	7.3	3.1
Premolars	0.5	0	0.5	2.1	0.5	0	7.4	9.0	2.1	12.7	3.7	4.8
Molars	0	2.2	14.3	0	1.1	0	0.5	29.1	2.7	8.2	2.2	0.5
Total	0.6	0.8	4.4	0.8	0.5	0	3.2	12.2	2.7	10.4	3.5	3.2

[a] BCT indicates buccal crown torque; DCT, distal crown tip; DR, distorotation; LCT, lingual crown torque; MCT, mesial crown tip; MR, mesiorotation.

Table 4. Prevalence of Bracket Transfer Errors and Their Directional Bias With Conventional IDB Silicone Tray (in %)[a]

	Dimensions											
	Mesiodistal (%)		Vertical (%)		Orobuccal (%)		Torque (%)		Rotation (%)		Tip (%)	
Tooth Type	Distal	Mesial	Occlusal	Gingival	Oral	Buccal	BCT	LCT	MR	DR	MCT	DCT
Incisors	0	0.5	0	0	0	0	0.5	1.6	1.1	1.1	2.2	1.1
Canines	0	0	0	0	0	0	0	1.1	3.2	0	2.2	0
Premolars	0	0	0	0	0	0	0	1.1	1.1	0.6	0	0
Molars	0	0.6	0	0	0	0	0.6	0	0	1.1	0	1.1
Total	0	0.3	0	0	0	0	0.3	0.9	1.1	0.8	0.9	0.6

[a] BCT indicates buccal crown torque; DCT, distal crown tip; DR, distorotation; LCT, lingual crown torque; MCT, mesial crown tip; MR, mesiorotation.

found in the mesiodistal direction and for rotation, particularly for canines. An explanation may be the uneven contact of the bracket base on the curved tooth surface and the resulting rotation around the buccal crest depending on the exact location of the finger pressure applied during the curing process and the flexibility of the tray material.[22]

Since the 3D-printed tray is of hard consistency and does not have defined areas of different elastic properties as suggested by Jungbauer et al.,[14] the compromise flexibility is implemented in the tray design with its optional segmentation along the breaking points. This leads to stress reduction in the tray itself during removal and, therefore, helps to avoid attachment debonding. Yet, regarding the high clinical acceptance of the conventional two-layered tray, better transfer results with Polyjet 3D-printed trays may be achieved using more materials of different elastic properties and an adapted tray design. However, further studies are needed.

A limitation to the current study may be inaccuracies caused by the multiple approximations of the real object's surfaces in a digital workflow starting with distortions caused during the intraoral scan,[26,27] the subsequent conversion into STL-files,[28] followed by inaccuracies before and during rapid prototyping. These are dependent on the slicer software, the resolution of the printer, printing orientation, support configuration, and the post-printing procedure.[24,29] Additionally, all IDB trays can be subject to the risk of human error by too much finger pressure or excessive composite application, which, if not removed before light curing, may lead to further distortions. Still, different results may be achieved under in-vivo conditions. Despite the advantages of a digital workflow, the conventional silicone tray yielded slightly better results in all dimensions. Further improvements of the 3D-printed IDB tray need to be investigated, such as the combination of multiple materials with different elastic properties when using Polyjet printing technology and an adapted tray design according to the chosen materials.

Table 5. *P* Values Calculated Using a Mixed Model to Detect Whether One Factor or an Interaction of Two Factors Significantly Influenced the Bracket Positions for Linear (mm) and Angular (°) Measurements

Factor(s)	*P* Values (mm)	*P* Values (°)
Tray versions[a]	.577	.004*
Tray versions x tooth groups[b]	.098	.794

[a] 3D-printed tray and conventional silicone.
[b] Interaction (x) between two factors on linear and angular measurements.
* $P < .05$ indicates statistical significance.

CONCLUSIONS

- The 3D-printed and the conventional tray are more accurate in the linear dimension than in the angular dimension. A significant difference between the trays for angular measurements was observed.
- Anterior teeth showed fewer transfer errors than posterior teeth using the 3D-printed tray. For the silicone tray, incisors were more frequently affected by transfer errors, followed by canines.

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