DOI: 10.4274/TurkJOrthod.2022.2022.34

TURKISH JOURNAL of ORTHODONTICS

Original Article

Transfer Accuracy of Three Indirect Bonding Trays: An *In Vitro* Study with 3D Scanned Models

Hilal Gündoğ[1], Ayça Arman Özçırpıcı[2], Hande Pamukçu[2]

[1]Private Practice, Ankara, Turkey
[2]Department of Orthodontics, School of Dentistry Başkent University, Ankara, Turkey

Cite this article as: Gündoğ H, Arman Özçırpıcı A, Pamukçu H. Transfer Accuracy of Three Indirect Bonding Trays: An *In Vitro* Study with 3D Scanned Models. *Turk J Orthod.* 2023; 36(1): 1-9

Main Points

- 3D-printed transfer trays were more successful than double vacuum formed and transparent silicone trays for transfer accuracy.
- Deviations were within the clinically acceptable limit for all transfer trays in the horizontal, vertical and transverse planes.
- Deviations in the molars were greater than those in the other tooth groups.
- Bracket deviations were generally toward the buccal direction.

ABSTRACT

Objective: The goal of the current study is to compare the transfer accuracy of two different conventional indirect bonding trays with 3D-printed trays.

Methods: Twenty-two patients' upper dental models were duplicated, scanned and brackets were bonded digitally. Different indirect bonding trays (double vacuum formed, transparent silicone and 3D-printed) were prepared according to three groups. These trays were used for the transfer of the brackets to the patients' models, then models with brackets were scanned. GOM Inspect software was used for the superimposition of virtual bracket setups and models with brackets. A total of 788 brackets and tubes were analyzed. Transfer accuracies were determined according to the clinical limit of 0.5 mm for linear and 2° for angular measurements.

Results: 3D-printed trays had significantly lower linear deviation values than other trays for all planes ($p<0.05$). 3D-printed trays have significantly lower torque and tip deviation values than other groups ($p<0.05$). Transfer deviations were within the clinically acceptable limit for all transfer trays in horizontal, vertical and transverse planes. Deviation values of the molars were higher than those of the other tooth groups for all trays in the horizontal and vertical planes ($p<0.05$). Brackets were generally deviated toward the buccal direction in all tray groups.

Conclusion: The transfer accuracy of 3D-printed transfer trays was more successful than the double vacuum formed and transparent silicone trays in the indirect bonding technique procedure. Deviations in the molar group were greater than those in the other tooth groups for all transfer trays.

Keywords: Indirect bonding, transfer tray, 3D printed tray

INTRODUCTION

One of the main purposes of orthodontic treatment is to align the teeth by placing them in the correct position in the alveolar bone. For this purpose, a wide variety of appliances and different bonding techniques have been used over the years. Accurate placement of brackets is an important factor for the success of the treatment and the incorrect location of brackets can cause undesirable movements of the teeth and a longer treatment time.

Silverman and Cohen[1] developed the indirect bonding technique (IDB) to enhance the accuracy and efficiency of bracket placement in 1972. Thomas[2] improved this bonding method by adding customized-bracket bases using composite resins for bonding brackets on the patient's model. Swetha et al.[3] found that the bond strengths

Corresponding author: Hilal Gündoğ, e-mail: hilalgundog@gmail.com

Received: April 24, 2022
Accepted: June 3, 2022
Epub: March 10, 2023
Publication Date: March 21, 2023

were increased with Thomas' method. Numerous studies have been conducted on the effectiveness of the IDB method and this technique has proven to be an effective technique for accurate bracket bonding.[4-6] Additionally, IDB technique has different advantages such as having shorter clinical time, close bond strength to the direct method and being more comfortable for patients.[7,8]

There are different materials and techniques for manufacturing IDB transfer trays. In the classical technique of IDB, brackets are positioned on stone casts and transfer trays are constructed from opaque or transparent silicones, double or single vacuum formed sheets with different thickness.[9,10] With the developing technology, there has been digital progress in the field of orthodontics and IDB techniques have also been digitized. Different companies offer three-dimensional (3D) computer-aided design and computer-aided manufacturing (CAD-CAM) methods for the production of IDB transfer trays. There are various software allowing semi-automatic placement of brackets and the digital design of IDB trays. These trays are usually produced by 3D printing.

There are several advantages of 3D-printed trays over classical IDB transfer trays. The most important advantage of these trays is the all-digital production process; trays can be standardized and the margin of error is minimized.[11] In this method, the need for a physical bracket transfer model is eliminated. Treatment outcome predictions can be made with the features of the software. Besides these advantages, there is a need for a careful technician or clinician who is well-trained in the use of the software used in the digital bonding and design of the 3D-printed tray.

Different IDB techniques were used when comparing transfer accuracies.[10,12-15] Most studies compared the transfer accuracy of IDB methods with direct bonding techniques.[16,17] However, there are fewer studies in the literature comparing 3D-printed trays with conventional IDB transfer trays.[4-6,12-15]

Therefore, this study aimed to compare the transfer accuracy of two conventional IDB transfer trays with 3D-printed trays.

METHODS

This study was approved by Başkent University Medical and Health Sciences Research Board and Ethics Committee (Project number: D-KA20/06) and supported by Başkent University Research Fund. A power analyis was performed by the G*Power software (vers 3.1.9.2; Axel Buchner, Universität Düsseldorf, Düsseldorf, Germany). According to sample calculation using measurements reported by a previous study, 75 brackets for each group were needed to obtain a statistical significance of at least 0.5 mm or 2° difference in terms of transfer error at 80% power and 5% error.[18] Assuming possible drop-out, it was planned to bond twelve upper teeth (first molar to first molar) of 22 patients in every group. Pretreatment upper dental casts of 22 cases were selected from the archive of Başkent University, Department of Orthodontics. The inclusion criteria were permanent dentition with minor crowding (Little's Irregularity Index <3) in the upper dental arch, no missing teeth, no prosthetic restorations, no dental anomalies and no fixed retainers. The selected casts were scanned with a 3 Shape scanner (TRIOS MOVE+, 3Shape Dental Systems, Copenhagen, Denmark) using the same scanning specifications. Twenty-two models duplicated with silicone impression material and 66 models were obtained. All models were cleaned with water and stored in a dry place until the bonding procedure.

Digital models were imported to 3Shape OrthoAnalyzer™ software (3Shape A/S, Copenhagen, Denmark) for virtual bracket placement (Figure 1). 0.018-inch slot brackets and tubes (Mini Master, American Orthodontics, Washington, DC, USA) were selected from the bracket library of the software. The bonding module of the software was semi automatically positioned the brackets and tubes on digital models and minor adjustments were performed by the same author (HG). These digitally bonded models in stereolithography (SLA) format served as reference (before) models for all groups (Figure 1).

Three different indirect bonding trays (double vacuum formed/Group 1, 3D-printed/Group 2, and transparent silicone/Group 3) were prepared (Figure 2). Digital models including the brackets were printed with a 3D printer (Formlabs Form 3, Somerville, MA, USA) using dental resin material (Formlabs, Somerville, MA, USA) for Groups 1 and 3.

In Group 1, double-vacuum trays were produced in a thermoforming device (Erkodent, Erkopress Comotion, Wembley, Australia) with a soft vacuum form (2 mm, Erkodent Erkoflex, Pfalzgrafenweiler, Germany) and a hard vacuum form (0.5 mm, Erkodent Erkodur, Pfalzgrafenweiler, Germany) (Figure 2). In Group 2, transfer trays were designed digitally with ApplianceDesigner™ software (3Shape A/S, Copenhagen, Denmark) and printed with a 3D printer (Formlabs Form 3, Somerville, MA, USA) using laser SLA technology (Figure 2). A flexible, biocompatible Class I resin material (Formlabs IBT, Somerville, MA, USA) was used for the fabrication of the transfer trays using laser SLA technology.

Transfer trays of Group 3 were prepared from transparent silicone impression material (Memosil 2, Heraeus Kulzer, Wehrheim, Germany) (Figure 2) on the resin models. First, the brackets, then the occlusal and lingual surfaces were coated with silicone, and transfer trays were prepared with 3-4 mm thickness. The edges of the trays were shaped with a scalpel to expose the hooks of the brackets, washed and dried with oil-free air.

All transfer trays were numbered according to group. Brackets and tubes were placed manually in the wells of the trays, then the brackets' bases were cleansed with pure alcohol. Each tray was sectioned at the midline to facilitate the bonding procedure.

All bonding procedures of this study were carried out by the same operator with 4 years of experience in the IDB. For bonding of the brackets to the duplicated models, enough light-cured adhesive (Transbond XT, 3M Unitek, Monrovia, CA, USA) was applied to the base of the brackets and a thin layer of primer (Transbond XT, 3M Unitek, Monrovia, CA, USA) was used to disperse the adhesive. The transfer trays were fixed manually onto the models and cured with an LED curing light (Elipar S 10, 3M ESPE, Monrovia, CA, USA) for 45 seconds per tooth. After tray removal, brackets were light-cured for an additional 15 seconds per tooth. Models with brackets were covered with a thin layer of scan-spray (Blue Spray, Dreve/Dentamid, Unna, Germany) to minimize the reflection of the brackets, then the 'after' models were digitized with the same scanner.

"Before" and "after" models were superimposed and evaluated with GOM Inspect software (GOM, Braunschweig, Germany) by a trained observer (Figure 3). Measurements were carried out tooth by tooth. Individual teeth were superimposed with closest point matching "local best fit algorithm" of the software to ensure that the differences were be from the deviations in the bracket position (Figure 4). Twelve reference points on each bracket (occlusal and cervical edges of the mesio-occlusal bracket wing, occlusal and cervical edges of the disto-occlusal bracket wing, mesial edge of the mesio-occlusal bracket wing, distal edge of the disto-occlusal bracket wing, mesial edge of the mesio-cervical bracket wing, distal edge of the disto-cervical bracket wing, buccal edge of the mesio- and disto-occlusal bracket wing, buccal edge of the mesio and disto-cervical bracket wing), and six reference points on each tube (occlusal and cervical edges of the mesio-occlusal part of the tube, occlusal and cervical edges of the disto-occlusal part of the tube, mesial and distal edges of the middle of the tube) were determined on the before models, and alterations in the bracket positions were evaluated (Supplementary Table 1). The positional deviation on the X, Y, and

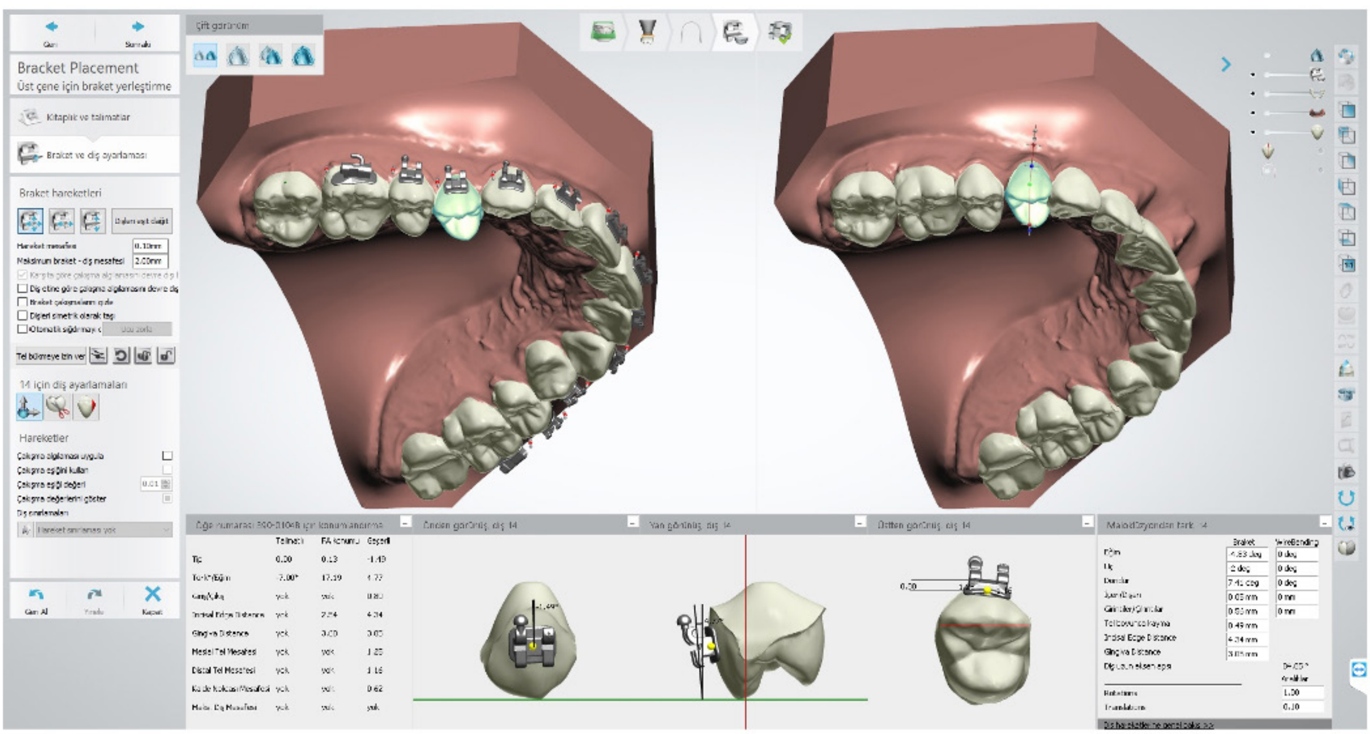

Figure 1. Virtual bracket placement in 3Shape OrthoAnalyzer™ software

Figure 2. Three different indirect bonding trays **A)** Double vacuum formed tray (Group 1), **B)** 3D-printed tray (Group 2), **C)** Transparent silicone tray (Group 3)

Z planes were calculated for every twelve points. The deviations on the X axis (horizontal) were assigned positive (+) values to the left, and negative (–) values to the right. The deviations on the Y axis (vertical) were assigned (+) values in a downward direction, and (–) values in an upward direction. On the Z axis (transversal), (+) values are assigned for outside deviations and (–) values for inside deviations. Angular deviations were evaluated on the XY (angulation/tip), YZ (torque), and XZ (rotation) planes. The linear bracket deviations were calculated in millimeters (mm) and angular deviations were calculated in degrees (°) within and outside the limits for each tooth.

To calculate intra-observer reliability 60 brackets from five different models were remeasured after a time interval of 20 days and the intraclass correlation coefficient (ICC) was calculated.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics for Windows 21.0 (IBM Corp., Armonk, NY, USA). Because the data did not have a normal distribution, the non-parametric Kruskal-Wallis H test was used for comparisons between groups. Intraclass correlation (ICC; two-way mixed) analysis was used for intra-examiner reliability. P<0.05 indicated a significant difference within the limits of 0.5 mm for linear and 2° for angular measurements, and p>0.05 indicated that there was no significant difference. These limits were selected from the professional standards of the American Board of Orthodontics (Aboriginal) objective grading system.[19]

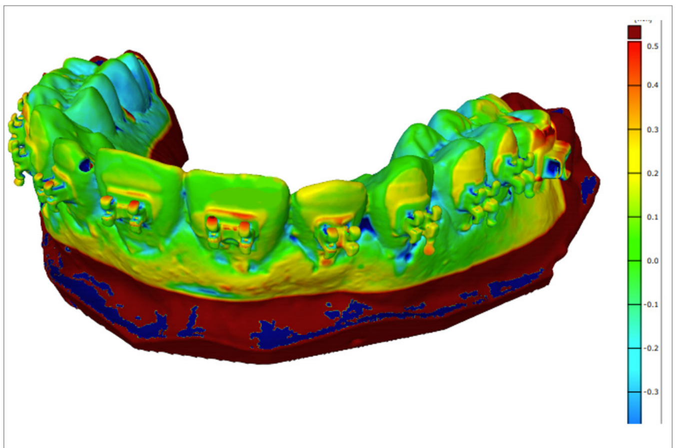

Figure 3. Superimposition of "before" and "after" models with GOM Inspect™ software

RESULTS

ICC values for intra-examiner reliability ranged from 0.993 to 0.998, which demonstrated excellent reliability. A total of 660 brackets and 132 tubes were bonded on 66 casts but four brackets were lost during transfer and not included in the analysis.

The linear and angular deviations are given in Table 1 as means and standard deviations. Transfer deviations were within the clinically acceptable range of 0.5 mm for all tray groups in all planes (Table 1). There were significant differences between the groups for the linear deviations in the horizontal, vertical and transverse planes (p<0.05) (Table 1). Group 2 had significantly lower mean linear deviation values for all planes than the other groups (p<0.05). There were significant differences in angular deviations between the groups for torque, rotation and tip (p<0.05) (Table 1). Group 2 had a significantly lower torque deviation value than Group 1 and Group 3 (1.49 ± 0.66). When the rotation values were examined, Group 3 had a significantly higher deviation value than Group 1 and Group 2 (3.46 ± 0.66). Group 2 had a significantly lower tip deviation value than the other groups (1.71 ± 0.59). The number and percentages of brackets that deviate from the acceptable limits of 0.5 mm and

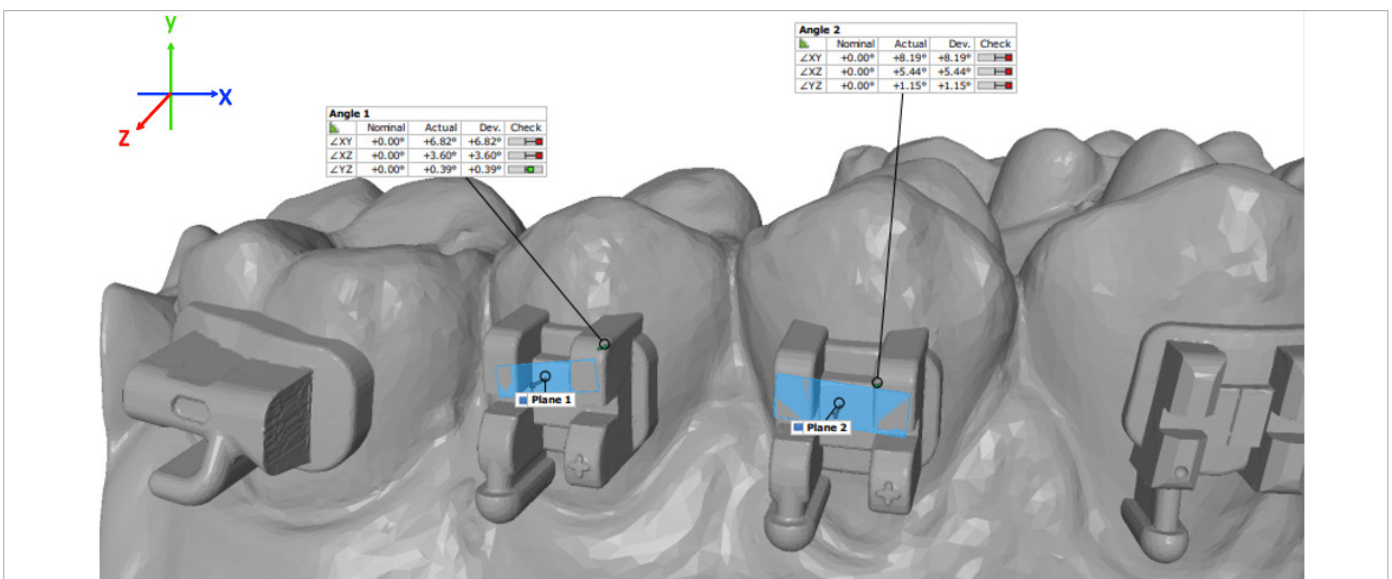

Figure 4. Measurement of deviations in the bracket position with GOM Inspect™ software

Table 1. Intergroup comparisons of transfer deviations of the brackets for linear and angular measurements

		n	Mean ± SD	Paired comparison†	p value
Horizontal (mm)	Group 1	262	0.11 ± 0.05		
	Group 2	264	0.05 ± 0.02	2-1	
	Group 3	262	0.14 ± 0.05	2-3	
Vertical (mm)	Group 1	262	0.22 ± 0.16		
	Group 2	264	0.08 ± 0.04	2-1	
	Group 3	262	0.24 ± 0.14	2-3	
Transversal (mm)	Group 1	262	0.09 ± 0.05		
	Group 2	264	0.06 ± 0.05	2-1	
	Group 3	262	0.09 ± 0.05	2-3	0.0001**
Torque (°)	Group 1	262	2.06 ± 0.34		
	Group 2	264	1.49 ± 0.66	2-1	
	Group 3	262	2.7 ± 0.45	2-3	
Rotation (°)	Group 1	262	2.64 ± 0.36		
	Group 2	264	2.38 ± 0.67	3-1	
	Group 3	262	3.46 ± 0.66	3-2	
Tip (°)	Group 1	262	2.11 ± 0.4		
	Group 2	264	1.71 ± 0.59	2-1	
	Group 3	262	2.58 ± 0.47	2-3	

SD, Standard deviation
†Significant difference between the numbered groups.
**$p<0.001$

2° were shown in Table 2. It was observed that the number and percentages of brackets outside the limits were low (Table 2).

Intra-group comparisons of tooth groups are shown in Table 3. Deviation values of the molars were significantly higher than those of the other tooth groups in the horizontal and vertical planes for all groups ($p<0.05$) (Table 3). In Group 1, deviation values of incisors and molars were significantly higher than those of the other tooth groups for torque, and deviation values of the incisors were significantly higher than those of the premolars and molars for rotation ($p<0.05$) (Table 3). In Group 1, deviation values of canines were significantly higher than molars and premolars for rotation ($p<0.05$) (Table 3). In Group 3, deviation values of incisors in the transversal direction were significantly lower than those of other tooth groups. There was no significant difference between the tooth groups for angular values in Groups 2 and Group 3 (Table 3) ($p>0.05$). Percentages of deviated brackets according to direction are given in Table 4. In the buccolingual direction, it was observed that 88.6% of the brackets in Group 1, 92% in Group 2 and 85.6% in Group 3 deviated toward the buccal.

DISCUSSION

The current study was conducted to compare the transfer accuracy of three different transfer trays which were not previously compared digitally. This is of clinical relevance, because double-vacuum formed and silicone materials are commonly used for the preparation of IDB transfer trays, but digital 3D-printed trays are fairly new. Double-vacuum form transfer trays began to be used in the 1990s.[9] Usually, the external layer of these type of trays is rigid, to provide stability, while the internal layer is soft, to allow easy removal of the tray from the brackets.[20-22] These transfer trays were used in Group 1. The innovative process originating from CAD-CAM has enabled a custom-made production in orthodontics. In Group 2, transfer trays were designed and printed digitally from a flexible biocompatible material by laser SLA technology. The transparent silicone impression material was used for the preparation of the transfer trays in Group 3 for using light-cured resin in all groups to provide standardization. These silicone trays were used in indirect bonding studies previously and have been proven to have dimensional stability with high positioning accuracy.[15,23]

In the literature, various methods have been used for the digitalization of study models, such as intraoral scanners, 3D-model scanners, photographs, micro-computed tomography (micro-CT) and cone beam CT (CBCT).[5,24-26] A study compared six intraoral scanners for scanning accuracy and found that all scanners produced acceptable results, but the Trios (3Shape A/S) scanner had the highest precision and reliable results. This scanner was used for the scanning of the models in the

Table 2. Number and percentages of brackets deviated from the acceptable limit

		n	Total	%
Horizontal (mm)	Group 1	5	262	0.02
	Group 2	1	264	0.00
	Group 3	11	262	0.04
Vertical (mm)	Group 1	12	262	0.05
	Group 2	3	264	0.01
	Group 3	11	262	0.04
Transversal (mm)	Group 1	4	262	0.02
	Group 2	0	264	0.00
	Group 3	2	262	0.01
Torque (°)	Group 1	22	262	0.08
	Group 2	19	264	0.07
	Group 3	22	262	0.08
Rotation (°)	Group 1	22	262	0.08
	Group 2	22	264	0.08
	Group 3	20	262	0.08
Tip (°)	Group 1	22	262	0.08
	Group 2	19	264	0.07
	Group 3	22	262	0.08

n, number of brackets deviated from limits

current study. The presence of brackets on the models could cause light reflection, which can lead to image distortion and artifacts.[27,28] A thin layer of scanning spray was applied by an experienced operator to prevent this reflection of the brackets and it is important to apply this spray homogeneously.[29] In this study, GOM software was used to measure the deviation of the brackets by superimposing the "before" and "after" models. Version 8 of this software has the ability to measure the data with a precision of 1 µm and enables a local best-fit to measure teeth separately.[25]

For standardization, conventional brackets with .018-inch slots (Mini Masters Series, American Orthodontics) were used in this study. However, other brackets could produce different results as the design and dimensions of brackets vary among different brands. Therefore, the results obtained from this study may not be valid for all bracket systems.

Bracket positions were found to be within acceptable limits for linear measurements in all groups, and the transfer accuracy of the examined trays was found to be high. While most studies considered these limits adequate, some studies have suggested that smaller deviations could be reliable.[15,24,30] Armstrong et al.[22] stated that deviations of 0.25 mm in incisors were clinically acceptable, whereas deviations of up to 0.5 mm in the other teeth were acceptable. Castilla et al.[12] found that differences of 0.13 mm in the opposite directions were clinically acceptable for adjacently positioned brackets.

The linear deviations for all the planes were less than 0.5 mm in all groups and this was consistent with the findings of many previous studies.[5,6,13,15] 3D-printed trays demonstrated lower linear deviation than the other groups for all planes. The angular deviations were higher than the linear deviations, and this was also similar to the previous studies' results.[5,6,13,15] The angular values of the silicone tray group were higher than those of the other groups.

A recent study by Niu et al.[13] compared double vacuum-formed and 3D-printed transfer trays for bracket transfer accuracy. Their double vacuum form transfer trays were fabricated (soft on the inside and hard on the outside) with a method similar to our method. Moreover, GOM Inspect software was used for the measurements in our study. They showed that 3D-printed transfer trays showed better transfer accuracy than the vacuum form transfer trays, and their linear control was superior to angular control. They also found that the linear values of 3D-printed trays were within the acceptable range suggested by the Aboriginal, while the angular values exceeded the limit. The direction of the deviated brackets in their study was mostly to the occlusal and buccal, which were similar to the findings of this study. The better results of 3D-printed trays can be attributed to the more precise digital design of these trays.

Chaudhary et al.[21] compared 3D-printed trays with the polyvinyl siloxane (PVS) transfer trays. While the position accuracy of the PVS transfer trays on the vertical plane was higher, 3D-printed trays showed higher positional accuracy in all other linear and angular measurements. Additionally, they found that most of the brackets deviated in the buccal direction, this was consistent with our study. They attributed this increased accuracy for the PVS group to the elasticity of the PVS material in contrast 3D-printed tray's more rigid resin or due to incorrect contouring around the edges of the tray. The 3D-printed tray material in our study was not rigid, had sufficient flexibility and stability.

Pottier et al.[15] compared transfer trays made of transparent silicone and 3D-printed trays, and found that both groups produced clinically acceptable values for bracket positions. But they found higher transfer accuracy with the transparent silicone trays, contrary to the results of the current study. The differences might have been caused by the different thickness of the silicone transfer trays, which was 5 mm in their study, on average 3-4 mm in this study. Additionally, silicone transfer trays in their study completely covered the brackets, resulting in reduced bracket mobility. However, 3D-printed transfer trays do not fully cover the brackets. These design differences of the transfer trays could create different results between 3D-printed trays and transparent silicone trays in terms of transfer accuracy.

Jungbauer et al.[6] investigated the selection of transfer trays according to the amount of crowding and suggested choosing a soft transfer tray in case of severe crowding. They advised the use of micro-CTs rather than 3D scanners for transfer accuracy

Table 3. Intra-group comparisons of transfer deviations of the brackets/tubes for linear and angular measurements (results were summarized for incisors, canines, premolars, and molars)

		Group 1			Group 2			Group 3		
		n	Mean ± SD	p value	n	Mean ± SD	p value	n	Mean ± SD	p value
Horizontal (mm)	Molar	43	0.24 ± 0.12	0.0001***	44	0.09 ± 0.09	0.0001***	43	0.29 ± 0.13	0.0001**
	Premolar	87	0.1 ± 0.05		88	0.05 ± 0.03		87	0.15 ± 0.05	
	Canine	44	0.09 ± 0.05		44	0.05 ± 0.04		44	0.1 ± 0.06	
	Incisor	88	0.08 ± 0.07		88	0.04 ± 0.02		88	0.1 ± 0.04	
	Total	262	0.13 ± 0.14		264	0.06 ± 0.06		262	0.16 ± 0.09	
Vertical (mm)	Molar	43	0.35 ± 0.18	0.0001***	44	0.22 ± 0.1	0.0001***	43	0.39 ± 0.14	0.0001***
	Premolar	87	0.21 ± 0.1		88	0.06 ± 0.04		87	0.22 ± 0.13	
	Canine	44	0.16 ± 0.09		44	0.06 ± 0.05		44	0.22 ± 0.15	
	Incisor	88	0.2 ± 0.07		88	0.04 ± 0.04		88	0.2 ± 0.17	
	Total	262	0.23 ± 0.2		264	0.1 ± 0.01		262	0.26 ± 0.19	
Transversal (mm)	Molar	43	0.13 ± 0.1	0.057	44	0.07 ± 0.03	0.002**	43	0.12 ± 0.11	0.266
	Premolar	87	0.08 ± 0.03		88	0.06 ± 0.03		87	0.08 ± 0.02	
	Canine	44	0.08 ± 0.02		44	0.07 ± 0.04		44	0.11 ± 0.05	
	Incisor	88	0.09 ± 0.1		88	0.04 ± 0.02		88	0.08 ± 0.03	
	Total	262	0.09 ± 0.07		264	0.06 ± 0.04		262	0.1 ± 0.06	
Torque (°)	Molar	43	2.2 ± 0.81	0.0001***	44	1.69 ± 1.03	0.276	43	3 ± 0.97	0.333
	Premolar	87	1.64 ± 0.69		88	1.27 ± 0.77		87	2.29 ± 1.09	
	Canine	44	1.78 ± 0.85		44	1.66 ± 0.86		44	2.6 ± 1.36	
	Incisor	88	2.55 ± 0.83		88	1.53 ± 0.71		88	3.01 ± 0.88	
	Total	262	2.04 ± 0.86		264	1.54 ± 0.85		262	2.73 ± 1.11	
Rotation (°)	Molar	43	2.38 ± 0.86	0.012*	44	2.57 ± 0.68	0.716	43	3.73 ± 0.92	0.183
	Premolar	87	2.33 ± 0.61		88	2.29 ± 0.92		87	3.51 ± 0.72	
	Canine	44	2.85 ± 1.03		44	2.34 ± 1.04		44	3.19 ± 0.46	
	Incisor	88	2.98 ± 0.53		88	2.41 ± 0.8		88	3.44 ± 0.43	
	Total	262	2.64 ± 0.82		264	2.4 ± 0.86		262	3.47 ± 0.68	
Tip (°)	Molar	43	2.49 ± 1.35	0.139	44	1.72 ± 0.98	0.606	43	2.87 ± 0.93	0.228
	Premolar	87	2.11 ± 0.46		88	1.88 ± 0.79		87	2.57 ± 0.48	
	Canine	44	2.16 ± 0.66		44	1.51 ± 0.77		44	2.58 ± 0.77	
	Incisor	88	1.89 ± 0.57		88	1.63 ± 0.59		88	2.44 ± 0.47	
	Total	262	2.16 ± 0.85		264	1.69 ± 0.62		262	2.61 ± 0.76	

SD, Standard deviation.
*p<0.05, **p<0.01, ***p<0.001

Table 4. Direction of deviated brackets according to groups (values are given as percentages)

	Direction											
	Mesiodistal		Buccolingual		Occlusogingival		Torque		Tip		Rotation	
Group	Mesial	Distal	Buccal	Lingual	Occlusal	Gingival	BCT	LCT	Mesial	Distal	Right	Left
Group 1	48.48	50.76	88.64	10.61	77.27	21.97	51.14	48.86	49.62	50.38	23.86	76.14
Group 2	42.42	55.3	92.05	7.2	51.14	40.15	53.79	46.21	48.86	51.14	52.27	47.73
Group 3	48.11	51.89	85.61	14.02	67.42	31.06	46.21	53.79	41.67	58.33	28.03	71.97

BCT, buccal crown torque; LCT, lingual crown torque measurements to be more reliable whereas usage of the micro-CT is limited to *in vitro* studies. Contrary to our findings, anterior teeth were found to be the most affected group by bonding errors, but in our study, molars were most affected. This difference could be due to methodological differences and minor crowding of our study groups. The high deviation of the molars can be attributed to the fact that these teeth are located at the end of the transfer trays, in this region more movements could occur during the bonding procedure. There could be bonding differences due to the design of the tubes, which are different and more voluminous than the brackets. Although molars are not evaluated in most of the IDB transfer accuracy studies, some studies found more transfer deviations in molars similar to our findings.[13]

In this study, linear deviations were mostly in the occlusal direction and this result was also consistent with some other studies.[12,14] Generally, brackets are expected to deviate in the occlusal direction as transfer trays are more likely to remain partly in the occlusal direction when they are not fitted completely. However, there are some studies showing more deviations toward the gingival direction, contradicting this finding.[24] This might be due to excessive pressure applied to the flexible transfer tray.

The common expectation for deviations in the buccolingual direction is the occurrence of deviation in the buccal direction, because of the excessive resin on the bracket base. In this study, most of the brackets deviated to the buccal direction, consistent with some studies in the literature.[18] However, movement in the opposite direction is also possible due to excessive sand blasting of the customized resin base.

Only one type of bracket and tube (Mini Master, American Orthodontics) were used in this study, but transfer accuracy in the IDB procedure could be affected by the design and volume of the brackets and tubes. Clinicians can use different brands of brackets and it would not be correct to generalize the results of this study for all bracket types. In future IDB studies, different types and brands of brackets can be compared with 3D-printed transfer trays.

A 3D scanner was used to scan the models with brackets and ICC values for intra-examiner reliability demonstrated excellent reliability in this study. Micro-CTs were found to be more reliable than the scanners in a previous study[6] but the use of micro-CTs increases study costs, and they are not suitable for *in vivo* studies. It is important to apply scanning spray homogeneously to minimize the reflection of the brackets and artifacts in the images. However, such homogeneity might not have been achieved completely as it was applied manually.[31] As a result, any unmeasurable error that may occur cannot be excluded.

This study was an *in vitro* investigation and transfer accuracy could be different in an *in vivo* evaluation. Some factors like isolation problems, saliva, difficulty to see and reach posterior region can affect the positioning accuracy *in vivo* conditions. In an *in vivo* study, the posterior brackets could have a higher incidence of positioning errors.

CONCLUSION

3D-printed transfer trays were more successful than double vacuum formed and transparent silicone trays for transfer accuracy in the IDB procedure. Transfer deviations were within the clinically acceptable limit for all transfer trays in horizontal, vertical and transverse planes. Deviations in the molar group were greater than those in the other tooth groups for all transfer trays. The deviations were generally toward the buccal direction in all groups.

Ethics

Ethics Committee Approval: This study was approved by Başkent University Medical and Health Sciences Research Board and Ethics Committee (Project number: D-KA20/06) and supported by Başkent University Research Fund.

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept-A.A.Ö.; Design-A.A.Ö., H.P; Supervision-A.A.Ö.; Materials-H.G; Data Collection and/or Processing-H.G.; Analysis and/or Interpretation-H.G.; Literature Review-H.G., H.P.; Writing-H.G., H.P.; Critical Review-A.A.Ö., H.P.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

Acknowledgments

The authors thank to ORTHODIGI Digital Orthodontic Services for 3D printing of the IDB transfer trays and to Aydın Koçdaş for his support in the digital work-flow of this study.

REFERENCES

1. Silverman E, Cohen M. A report on a major improvement in the indirect bonding technique. *J Clin Orthod*. 1975;9(5):270-276. [CrossRef]
2. Thomas RG. Indirect bonding: simplicity in action. *J Clin Orthod*. 1979;13(2):93-106. [CrossRef]
3. Swetha M, Pai VS, Sanjay N, Nandini S. Indirect versus direct bonding--a shear bond strength comparison: an in vitro study. *J Contemp Dent Pract*. 2011;12(4):232-238. [CrossRef]
4. Zhang Y, Yang C, Li Y, Xia D, Shi T, Li C. Comparison of three-dimensional printing guides and double-layer guide plates in accurate bracket placement. *BMC Oral Health*. 2020;20(1):127. [CrossRef]
5. Xue C, Xu H, Guo Y, et al. Accurate bracket placement using a computer-aided design and computer-aided manufacturing-guided bonding device: An in vivo study. *Am J Orthod Dentofacial Orthop*. 2020;157(2):269-277. [CrossRef]
6. Jungbauer R, Breunig J, Schmid A, et al. Transfer Accuracy of Two 3D Printed Trays for Indirect Bracket Bonding--An In Vitro Pilot Study. *Appl Sci*. 2021;11(13):6013. [CrossRef]
7. Suganya S. Measurement and Comparision of Bracket Transfer Accuracy of Five Indirect Bonding Techniques: An In Vitro study. 2017. [CrossRef]

8. Pamukcu H, Ozsoy OP, Dagalp R. In vitro and in vivo comparison of orthodontic indirect bonding resins: A prospective study. *Niger J Clin Pract*. 2018;21(5):614-623. [CrossRef]
9. Sondhi A. Efficient and effective indirect bonding. *Am J Orthod Dentofac Orthop*. 1999;115(4):352-359. [CrossRef]
10. Echarri P, Kim TW. Double transfer trays for indirect bonding. *J Clin Orthod*. 2004;38(1):8-13. [CrossRef]
11. Christensen LR, Cope JB. Digital technology for indirect bonding. *Seminars in Orthodontics*. 2018;24(4):451-460. [CrossRef]
12. 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(4):607-614. [CrossRef]
13. Niu Y, Zeng Y, Zhang Z, Xu W, Xiao L. Comparison of the transfer accuracy of two digital indirect bonding trays for labial bracket bonding. *Angle Orthod*. 2021;91(1):67-73. [CrossRef]
14. 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(5):549-555. [CrossRef]
15. Pottier T, Brient A, Turpin YL, et al. Accuracy evaluation of bracket repositioning by indirect bonding: hard acrylic CAD/CAM versus soft one-layer silicone trays, an in vitro study. *Clin Oral Investig*. 2020;24(11):3889-3897. [CrossRef]
16. Koo BC, Chung CH, Vanarsdall RL. Comparison of the accuracy of bracket placement between direct and indirect bonding techniques. *Am J Orthod Dentofac Orthop*. 1999;116(3):346-351. [CrossRef]
17. Deahl ST, Salome N, Hatch JP, Rugh JD. Practice-based comparison of direct and indirect bonding. *Am J Orthod Dentofaccial Orthop*. 2007;132(6):738-742. [CrossRef]
18. Grünheid T, Lee MS, Larson BE. Transfer accuracy of vinyl polysiloxane trays for indirect bonding. *Angle Orthod*. 2016;86(3):468-474. [CrossRef]
19. Casko JS, Vaden JL, Kokich VG, et al. Objective grading system for dental casts and panoramic radiographs. American Board of Orthodontics. *Am J Orthod Dentofacacial Orthop*. 1998;114(5):589-599. [CrossRef]
20. Silverman E, Cohen M, Gianelly AA, Dietz VS. A universal direct bonding system for both metal and plastic brackets. *Am J Orthod*. 1972;62(3):236-244. [CrossRef]
21. Chaudhary V, Batra P, Sharma K, Raghavan S, Gandhi V, Srivastava A. A comparative assessment of transfer accuracy of two indirect bonding techniques in patients undergoing fixed mechanotherapy: A randomised clinical trial. *J Orthod*. 2021;48(1):13-23. [CrossRef]
22. Armstrong D, Shen G, Petocz P, Darendeliler MA. A comparison of accuracy in bracket positioning between two techniques--localizing the centre of the clinical crown and measuring the distance from the incisal edge. *Eur J Orthod*. 2007;29(5):430-436. [CrossRef]
23. Nojima LI, Araújo AS, Alves Júnior M. Indirect orthodontic bonding--a modified technique for improved efficiency and precision. *Dental Press J Orthod*. 2015;20(3):109-117. [CrossRef]
24. Sachdeva RC. SureSmile technology in a patient--centered orthodontic practice. *J Clin Orthod*. 2001;35(4):245-253. [CrossRef]
25. Anh JW, Park JM, Chun YS, Kim M, Kim M. A comparison of the precision of three-dimensional images acquired by 2 digital intraoral scanners: effects of tooth irregularity and scanning direction. *Korean J Orthod*. 2016;46(1):3-12. [CrossRef]
26. Süpple J, von Glasenapp J, Hofmann E, Jost-Brinkmann PG, Koch PJ. Accurate Bracket Placement with an Indirect Bonding Method Using Digitally Designed Transfer Models Printed in Different Orientations-An In Vitro Study. *J Clin Med*. 2021;10(9):2002. [CrossRef]
27. Möhlhenrich SC, Alexandridis C, Peters F, et al. Three-dimensional evaluation of bracket placement accuracy and excess bonding adhesive depending on indirect bonding technique and bracket geometry: an in-vitro study. *Head Face Med*. 2020;16(1):17. [CrossRef]
28. Heo H, Kim M. The Effects of Orthodontic Brackets on the Time and Accuracy of Digital Impression Taking. *Int J Environ Res Public Health*. 2021;18(10):5282. [CrossRef]
29. Hack GD, Patzelt SBM. Evaluation of the accuracy of six intraoral scanning devices: an in-vitro investigation. *ADA Prof Prod Rev*. 2015;10(4):1-5. [CrossRef]
30. Kim YK, Kim SH, Choi TH, et al. Accuracy of intraoral scan images in full arch with orthodontic brackets: A retrospective in vivo study. *Clin Oral Investig*. 2021;25(8):4861-4869. [CrossRef]
31. Dehurtevent M, Robberecht L, Béhin P. Influence of dentist experience with scan spray systems used in direct CAD/CAM impressions. *J Prosthet Dent*. 2015;113(1):17-21. [CrossRef]

Supplementary Table 1. Definitions of measuring points on brackets and tubes

	Brackets
Point 1	Occlusal edge of the mesio-occlusal bracket wing
Point 2	Cervical edge of the mesio-occlusal bracket wing
Point 3	Occlusal edge of the disto-occlusal bracket wing
Point 4	Cervical edge of the disto-occlusal bracket wing
Point 5	Mesial edge of the mesio-occlusal bracket wing
Point 6	Distal edge of the disto-occlusal bracket wing
Point 7	Mesial edge of the mesio-cervical bracket wing
Point 8	Distal edge of the disto-cervical bracket wing
Point 9	Buccal edge of the mesio-occlusal bracket wing
Point 10	Buccal edge of the disto-occlusal bracket wing
Point 11	Buccal edge of the mesio-cervical bracket wing
Point 12	Buccal edge of the disto-cervical bracket wing
	Tubes
Point 1	Occlusal edge of the mesio-occlusal part of the tube
Point 2	Cervical edge of the mesio-occlusal part of the tube
Point 3	Occlusal edge of the disto-occlusal part of the tube
Point 4	Cervical edge of the disto-occlusal part of the tube
Point 5	Mesial edge of the middle of the tube
Point 6	Distal edge of the middle of the tube