Original Article

Bracket transfer accuracy with two different three-dimensional printed transfer trays vs silicone transfer trays

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ABSTRACT

Objectives: To compare the transfer accuracy of two different three-dimensional printed trays (Dreve FotoDent ITB [Dreve Dentamid, Unna, Germany] and NextDent Ortho ITB [NextDent, Soesterberg, the Netherlands]) to polyvinyl siloxane (PVS) trays for indirect bonding.

Materials and Methods: A total of 10 dental models were constructed for each investigated material. Virtual bracket placement was performed on a scanned dental model using OnyxCeph (OnyxCeph 3D Lab, Chemnitz, Germany). Three-dimensional printed transfer trays using a digital light processing system three-dimensional printer and silicone transfer trays were produced. Bracket positions were scanned after the indirect bonding procedure. Linear and angular transfer errors were measured. Significant differences between mean transfer errors and frequency of clinically acceptable errors (<0.25 mm/1°) were analyzed using the Kruskal–Wallis and χ^2 tests, respectively.

Results: All trays showed comparable accuracy of bracket placement. NextDent exhibited a significantly higher frequency of rotational error within the limit of 1° ($P = .01$) compared with the PVS tray. Although PVS showed significant differences between the tooth groups in all linear dimensions, Dreve exhibited a significant difference in the buccolingual direction only. All groups showed a similar distribution of directional bias.

Conclusions: Three-dimensional printed trays achieved comparable results with the PVS trays in terms of bracket positioning accuracy. NextDent appears to be inferior compared with PVS regarding the frequency of clinically acceptable errors, whereas Dreve was found to be equal. The influence of tooth groups on the accuracy of bracket positioning may be reduced by using an appropriate three-dimensional printed transfer tray (Dreve). (*Angle Orthod.* 2022;92:364–371.)

KEY WORDS: Indirect bonding; Virtual bracket placement; Transfer accuracy; 3D printing

INTRODUCTION

In fixed orthodontic therapy, brackets, bands, and buccal tubes are used to transfer force and torque to teeth, thereby inducing tooth movement. The accurate positioning of orthodontic brackets plays a crucial role because deviations from the correct bracket positions can lead to undesirable tooth movement, poor treatment results, and prolonged treatment time. Brackets and buccal tubes can be positioned on the teeth either directly or indirectly via a transfer aid (transfer tray). Advantages of indirect bonding compared with the direct bonding technique have been described in the literature and include, in particular, a higher accuracy of bracket position, reduced chair time, and a higher patient comfort.[1–7] In addition, computer-aided planning and manufacturing technology enables virtual planning of bracket positions. As a result of additive manufacturing (three-dimensional printing), cost-effective and easy manufacturing of bracket transfer splints is possible.[8] This new digital workflow has the potential to minimize positioning errors and increase treatment efficiency.

Accuracy of the final bracket position is defined as the deviation between the planned and actual position

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of the bracket. Error during data acquisition, transfer, processing, splint design, and the printing process as well as the material properties might influence the accuracy. To date, there are only a few studies available comparing the accuracy of bracket position using different indirect bonding three-dimensional printed trays.[9–14]

The primary objective of this study was to investigate the bracket transfer accuracy (bracket offset of bonded bracket position to designed bracket position in millimeters and degrees) of three-dimensional printed transfer trays in comparison with a PVS tray. As a secondary objective, the effect of different tooth groups (incisors, canines, premolars, molars) on the bracket transfer accuracy in comparison with PVS trays was analyzed.

MATERIALS AND METHODS

A manikin head was chosen to simulate an in vivo situation as accurately as possible. An upper jaw model with 16 plastic teeth (World Dental Federation [FDI] tooth notation) was digitized with a model scanner (S300 ARTI; Zirkonzahn, Gais, Italy) and imported into the software OnyxCeph (OnyxCeph 3D Lab, Germany). This scanned model provided the basis for the digital bracket construction and tray preparation. The following materials already approved for dental use were selected for the three-dimensional printed trays: Dreve FotoDent ITB (Dreve Dentamid, Unna, Germany) and NextDent Ortho ITB (NextDent, Soesterberg, the Netherlands).

Preparation of the Models and Transfer Trays

For construction of the dental models for the manikin head, the initially scanned maxillary model was duplicated using a silicone impression and plaster, resulting in 10 models for each material group (Dreve, NextDent, PVS). Duplicate models were conically trimmed and extended with an adapter for the manikin head (Figure 1).

Virtual bracket placement was performed on teeth 16–26 with data sets of self-ligating straight-wire brackets (0.022 $\times$ 0.028) and buccal tubes (BioQuick; Forestadent, Pforzheim, Germany). All brackets and buccal tubes were manually readjusted and aligned in all three dimensions according to the straight-wire concept. The final bracket design represented the reference data set.

The design of the three-dimensional printed bracket transfer trays was carried out using the OnyxCeph3TM (OnyxCeph 3D Lab, Chemnitz, Germany) software module “Bonding Trays 3D." The trays were configured with 0.05-mm distance to the tooth crowns, a material thickness of 1.3 mm, and a 1.5-mm slot overlap in the bracket region. A flat design in the occlusal region was chosen to allow three-dimensional printing without support structures directly on the printer’s platform. The designed bracket transfer trays were exported as a Standard Triangle Language (STL) file and aligned flat on the building platform using Autodesk Netfabb Premium software (version 2019.0; Autodesk, Mill Valley, Calif). Product-specific print parameters for the three-dimensional printing materials were applied according to the manufacturer’s specifications. Slicing was performed according to the manufacturer’s settings with a corresponding layer thickness of 50 μm. A total of 10 transfer trays with each material (Dreve, NextDent) were printed with a digital light processing (DLP) system three-dimensional printer (D20 II; Rapidshape, Heimsheim, Germany). Postprocessing was carried out according to manufacturer’s specifications, including cleaning of the trays for 6 minutes in isopropanol (96%) activated with ultrasound followed by drying. Trays were postcured using the Otoflash G171 (NK-Optik, Baierbrunn, Germany) with 2 $\times$ 2000 flashes under a nitrogen atmosphere.

To produce the 10 silicone trays, physical models (Grey Resin; Formlabs, Berlin, Germany) were necessary. Virtually planned bracket positions were mapped on a physical model. Positioning aids were calculated using Kylix 3D (OnyxCeph3TM). The digital model data set with positioning aids was printed using a stereolithography (SLA) printer (Form2; Formlabs; Figure 1). Based on these tooth models, the silicone transfer trays were made using PVS putty (Tresident 2000K; Schütz Dental, Rosbach, Germany) according to previously described recommendations.[15–17]

Bonding and Scanning of the Bonded Models

The bonding process was likewise performed for all material groups. A thin layer of composite luting cement was applied on the base of each bracket and buccal tube (RelyX Unicem 2 Automix; 3M, Seefeld, Germany). Transfer trays were positioned on the maxilla attached to the phantom patient, and the optimal fit of the tray was verified with a mirror. The composite luting cement was cured for 10 seconds at each tooth before the transfer splint was removed and postcured for another 10 seconds.

After the bonding process, the brackets were scanned with an industrial three-dimensional scanner ATOS 5 (GOM, Braunschweig, Germany) with a resolution of 10 μm. Scans and the reference data set were aligned (OnyxCeph 3D Lab software) over 10 visually identifiable anatomical points in a radius of 1.0 mm using a best-fit algorithm. Linear (mesiodistal, vertical, buccolingual) and angular offset (angulation,

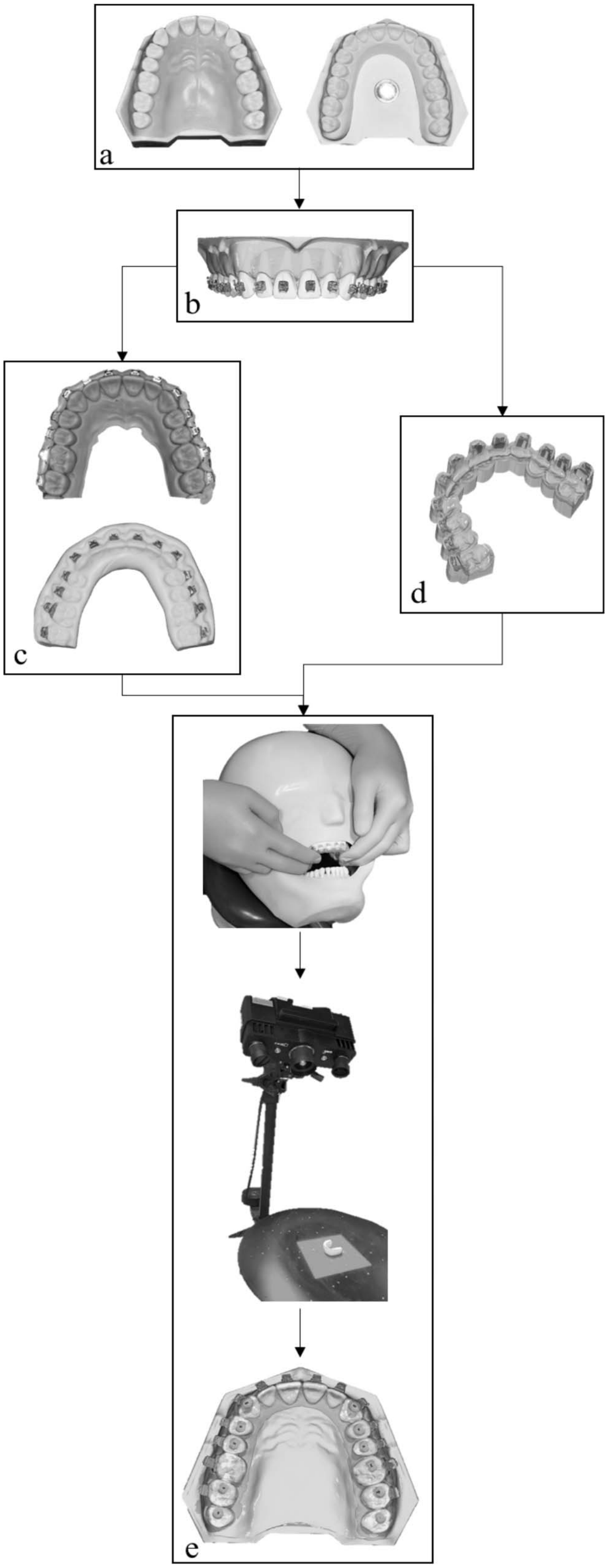


Figure 1. Workflow for the different material trays. (a) Dental models. (b) Virtual bracket placement. (c) Silicone trays. (d) Three-dimensional printed transfer trays of each material. (e) Bonding, scanning of the brackets, and overlay with the reference data set.

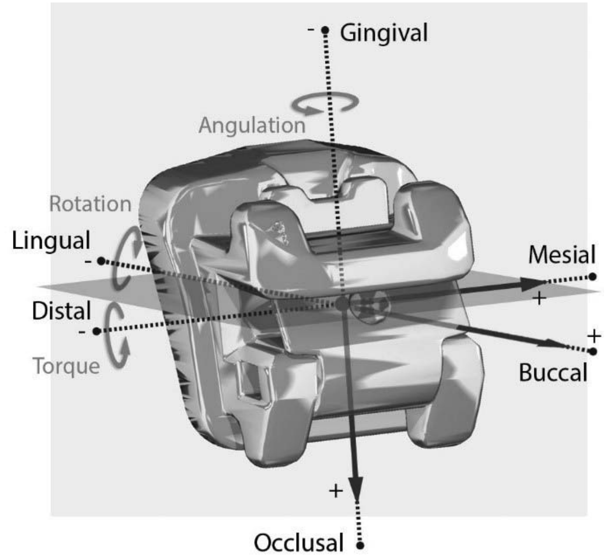


Figure 2. Defined coordinate system for analyzing the offset of the overlay of the scan and the reference data set. Mesiodistal: Mesial(+), Distal(–). Vertical: Occlusal(+), Gingival(–). Buccolingual: Buccal(+), Lingual(–). Angulation: mesial root tip(+), distal root tip(–). Torque: buccal crown torque(+), lingual crown torque(–). Rotation: mesiobuccal(+), mesiolingual(–).

rotation, torque) between the scanned and reference data set were calculated (Figure 2).

Clinically acceptable limit values were analyzed based on the American Board of Orthodontics (ABO) objective grading system for dental casts. Deviations of $\leq$0.5 mm and 2° were defined as clinically acceptable.[9,11] To account for the possibility of two adjacent brackets deviating in opposite directions, the limit of clinical acceptability in the present study was set at 0.25 mm and 1°.

For the calculation of linear and angular offsets, as well for calculating the frequency of exceeding clinically acceptable limit values, all values were set to the amount. Therefore, we have included that various directional deviations (+/–) have no influence on the actual deviation. This accounted for the possibility that some brackets have a positive offset of, for example, +1 mm, and others a negative offset of –1 mm, resulting in a higher distance of 2 mm comparing these two bracket positions. In addition, the directional bias of the offset was analyzed.

A power of 0.99 was analyzed using G*Power1 (version 3.1; Düsseldorf, Germany). Statistical analysis was carried out with IBM SPSS Statistics version 26 (IBM, Armonk, N.Y.). Metric data were tested for normal distribution using the Shapiro-Wilk test. Significant differences in metric data were analyzed using the Kruskal-Wallis test and a post hoc Dunn-Bonferroni test. Nominal data were tested for significant differences using the Pearson χ^2 test. A P value $<$.05 was considered significant.

Table 1. Mean (±SD) Difference in mm and Degrees Between the Simulated Bracket Position and the Postoperatively Scanned Bracket Position. Significant differences are represented by homogenous subgroups (α=0.05). Numbers with the same letters do not differ significantly. Numbers with different letters differ significantly. PVS and Dreve exhibited significant differences in the buccolingual and vertical direction.

		Material						
		NextDent		PVS		Dreve		
Dimension		Mean	±SD	Mean	±SD	Mean	±SD	*P*-Value
Linear error (mm)	Mesiodistal	0.07[a]	0.05	0.08 [a]	0.06	0.07 [a]	0.04	.49
	Vertical	0.10 [ab]	0.07	0.07[b]	0.06	0.11 [a]	0.06	**.001**
	Buccolingual	0.09 [ab]	0.06	0.10[a]	0.05	0.08[b]	0.06	**.02**
Angular error (°)	Angulation	0.51 [a]	0.47	0.43 [a]	0.32	0.48 [a]	0.36	.43
	Torque	0.62 [a]	0.38	0.59 [a]	0.46	0.69 [a]	0.43	.08
	Rotation	0.43 [a]	0.31	0.40 [a]	0.26	0.38 [a]	0.27	.63

Bold signifies significant difference.

RESULTS

In total, 360 brackets were bonded using the three different material trays investigated (120 brackets each on 10 upper jaw models, teeth 16–26). No bracket loss occurred during the entire study. Table 1 shows the mean deviation of the bracket position of the different tray materials between the digital design and the scanned bracket position after bonding. All bonding trays provided accurate bracket placement. The mean deviations of the bracket positions of all materials investigated were in a similar range (0.07–0.11 mm/0.38–0.69°). Significant differences were observed between the PVS and Dreve in the vertical ($P = .01$) and buccolingual ($P = .02$) directions.

The mean deviations of the bracket positions of the different tooth types are summarized in Table 2. Molars almost always exhibited the highest mean values regardless of the tray used. Significant differences between the tooth groups were only observed in the linear values. Although PVS tray values showed significant differences between the tooth groups in all linear dimensions, Dreve tray values exhibited a significant difference in the buccolingual direction only.

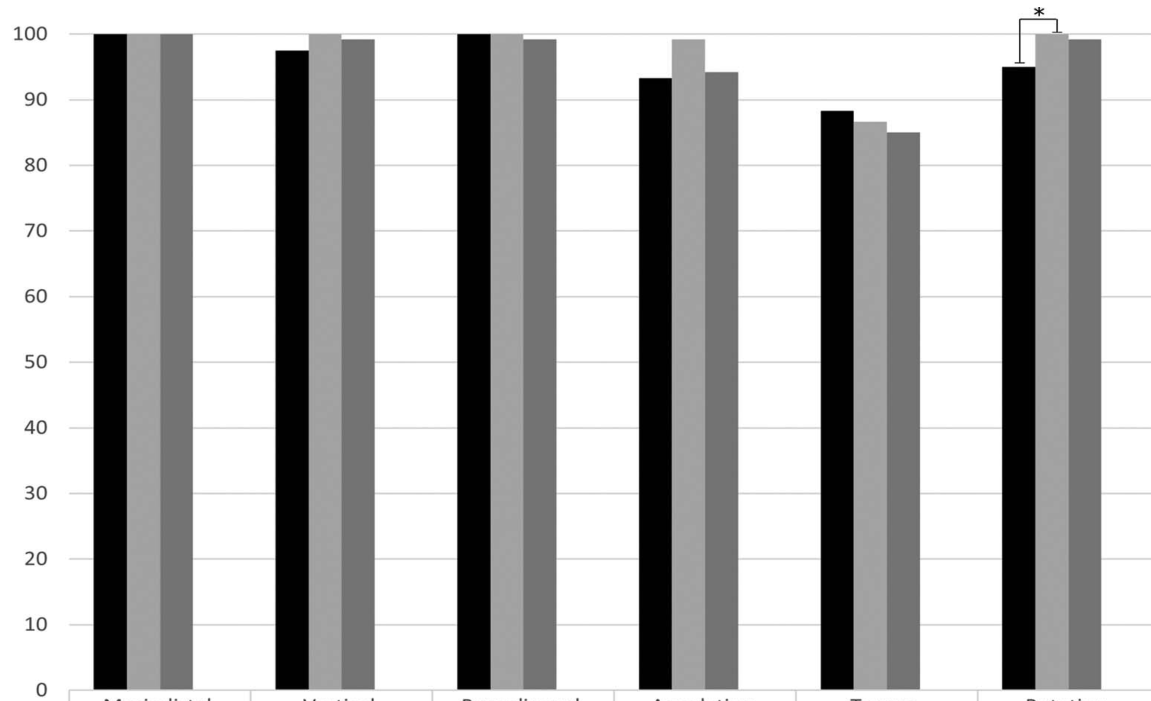
Clinically acceptable limits were more frequently exceeded by angular compared with linear values. PVS tray values were most often within the range of clinically acceptable limits followed by Dreve and NextDent (Figure 3). Compared with the PVS tray, NextDent significantly exceeded the critical limit of 1° more frequently regarding the rotation criterion.

Molars exceeded the range of clinically acceptable transfer errors more frequently, followed by canines, incisors, and premolars. However, a significant difference between the tooth groups was not observed (Figure 4).

Table 2. Mean (±SD) Difference in mm and Degrees Between the Simulated Bracket Position and the Postoperative Scanned Bracket Position of the Different Tooth Types Subdivided by the Tray Materials Investigated. Significant differences are represented by homogenous subgroups (α=0.05). Numbers with the same letters do not differ significantly. Numbers with different letters differ significantly. Significant differences could be observed in the linear directions between the different tooth types.

			Molars		Premolars		Canines		Incisors		
Material			Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	*P*-Value
NextDent	Linear error (mm)	Mesiodistal	0.14[a]	0.06	0.07[b]	0.04	0.06[b]	0.04	0.05[b]	0.04	**.001**
		Vertical	0.11[a]	0.11	0.10 [a]	0.05	0.09 [a]	0.07	0.09 [a]	0.05	.79
		Buccolingual	0.15[a]	0.04	0.10[b]	0.05	0.03[c]	0.03	0.08[b]	0.05	**.001**
	Angular error (°)	Angulation	0.55 [a]	0.32	0.47 [a]	0.34	0.50 [a]	0.35	0.48 [a]	0.27	.81
		Torque	0.66 [a]	0.39	0.53 [a]	0.34	0.75 [a]	0.44	0.62 [a]	0.36	.29
		Rotation	0.55 [a]	0.35	0.40 [a]	0.30	0.40 [a]	0.27	0.40 [a]	0.31	.39
PVS	Linear error (mm)	Mesiodistal	0.11[a]	0.06	0.09[a]	0.06	0.08[ab]	0.06	0.05[b]	0.04	**.003**
		Vertical	0.10[a]	0.05	0.07[ab]	0.04	0.06[b]	0.06	0.07[ab]	0.05	**.04**
		Buccolingual	0.12[a]	0.06	0.12[a]	0.06	0.05[b]	0.04	0.10[a]	0.05	**.001**
	Angular error (°)	Angulation	0.39 [a]	0.32	0.37 [a]	0.28	0.45 [a]	0.24	0.49 [a]	0.28	.20
		Torque	0.75 [a]	0.51	0.50 [a]	0.38	0.66 [a]	0.47	0.57 [a]	0.42	.21
		Rotation	0.46 [a]	0.27	0.38 [a]	0.26	0.48 [a]	0.30	0.34 [a]	0.30	.17
Dreve	Linear error (mm)	Mesiodistal	0.08 [a]	0.07	0.06 [a]	0.04	0.06 [a]	0.04	0.07 [a]	0.03	.37
		Vertical	0.13 [a]	0.05	0.10 [a]	0.06	0.13 [a]	0.05	0.10 [a]	0.06	.05
		Buccolingual	0.17[a]	0.04	0.06[bc]	0.03	0.03[c]	0.02	0.08[b]	0.04	**.001**
	Angular error (°)	Angulation	0.53 [a]	0.30	0.42 [a]	0.32	0.39 [a]	0.42	0.57 [a]	0.38	.08
		Torque	0.57 [a]	0.26	0.68 [a]	0.46	0.65 [a]	0.32	0.80 [a]	0.50	.46
		Rotation	0.42 [a]	0.26	0.39 [a]	0.28	0.44 [a]	0.28	0.33 [a]	0.26	.43

Bold signifies significant difference.



	Mesiodistal	Vertical	Buccolingual	Angulation	Torque	Rotation
■ NextDent (n=120) in %	100	97.5	100	93.3	88.3	95.0
■ PVS (n=120) in %	100	100	100	99.2	86.7	100
■ Dreve (n=120) in %	100	99.2	99.2	94.2	85.0	99.2
p- value	–	0.17	0.37	0.06	0.75	0.01

Figure 3. Prevalence of the clinically acceptable transfer errors of the different tray materials. NextDent significantly exceeded the critical limit of 1° more frequently compared with PVS. *$P = .01$.

Table 3 summarizes the directional bias of transfer errors in percent. All materials exhibited a comparable negative or positive deviation. A maximum bias of 98.3% was observed with Dreve regarding the torque criterion.

DISCUSSION

All transfer trays showed accurate bracket placement. Significant differences were observed for the mean vertical and buccolingual errors between the PVS tray and Dreve tray, once for the benefit of the PVS tray and once for the benefit of the Dreve tray. Mean values for NextDent were in between and showed no significant differences compared with the other materials investigated. Thus, in general, all materials were found to have comparable accuracy, with advantages in certain sections.

To date, only a few publications on this topic are available, reporting inconsistent results.[9–13] Using a study design similar to that of the current study, Pottier et al. investigated three-dimensional printed trays vs PVS trays.[11] They showed that PVS trays were more precise than three-dimensional printed trays as they observed significantly lower values for PVS trays.[11] However, comparing results of the mean bracket placement error to the current study, all values of the three-dimensional printed trays reported by Pottier et al. were up to twice as high. Based on these findings, it may be assumed that the three-dimensional transfer tray used in the present study achieved a higher accuracy in bracket placement compared with Pottier et al.

Niu et al. examined the bracket accuracy of three-dimensional printed vs double vacuum-formed trays.[10] They reported that the three-dimensional printed trays had higher transfer accuracy than the double vacuum-formed trays.[10] Unlike in the current study, they used double vacuum trays as a reference, which have been proven to be less accurate than PVS trays.[15] The transfer accuracy of the three-dimensional printed material trays in terms of the linear errors observed in the current study were comparable with those reported by Niu et al.[10] However, lower mean angular errors were observed, indicating better angular control during bracket placement. Compared with this study, similar results regarding the rate of exceeding clinically relevant limits (ABO limits of 1°/2.5 mm) were observed by Niu et al. Although the frequency in the linear dimensions was comparable (Niu et al., 97.5%–100%;

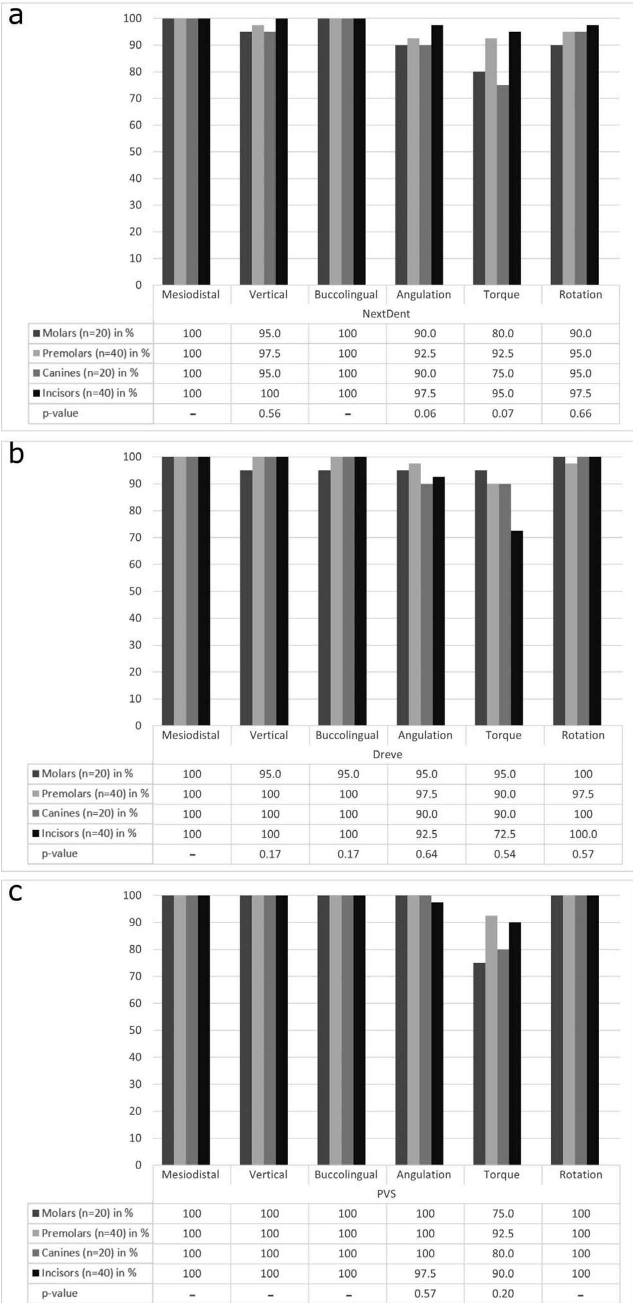


Figure 4. Prevalence of the clinically acceptable transfer errors of the tooth types and tray materials investigated. (a) NextDent. (b) Dreve. (c) PVS.

present study, 95.4%–100%), it was substantially lower in the angular dimension (Niu et al., 50.9%–85.2%; present study, 85.9%–99.2%).[10,11]

The higher accuracy of bracket placement observed in the present study compared with Pottier et al., as well as the better angular control compared with Niu et al., may be attributed to numerous factors: bracket transfer skills, tray design, scanners, different tray materials, software settings, or the three-dimensional printers used. To eliminate potential operator-dependent variability, bracket placement was performed by only one operator in the current study.

Table 3. Frequencies of Directional Bias of the Different Tray Materials Investigated

	Materials		
Dimension[a]	NextDent	PVS	Dreve
Mesiodistal (%)			
Mesial (+)	65.0	68.3	55.0
Distal (−)	30.0	27.5	41.7
Vertical (%)			
Occlusal (+)	20.8	26.7	11.7
Gingival (−)	75.8	69.2	85.0
Buccolingual (%)			
Buccal (+)	14.2	15.0	13.3
Lingual (−)	83.3	79.2	84.2
Angulation (%)			
MRT (+)	17.5	42.5	25.0
DRT (−)	80.0	52.5	69.2
Torque (%)			
BCT (+)	96.7	83.3	98.3
LCT (−)	1.7	15.8	0
Rotation (%)			
m-b (+)	38.3	41.7	43.3
m-l (−)	50.0	54.2	44.2

[a] BCT indicates buccal crown torque; DRT, distal root tip; LCT, lingual crown torque; m-b, mesiobuccal; m-l, mesiolingual; and MRT, mesial root tip.

In contrast to the present study, Niu et al. used a semi-enclosed design that covered the two sides and the occlusal surface of the bracket, but not the gingival and undercut surfaces. They concluded that their design might have lowered the accuracy of bracket positioning in three dimensions, particularly in the angular control. As a fully covered tray design was used, this may explain the lower angular errors observed in the present study.

To minimize errors in the scanning process, an industrial ATOS 5 three-dimensional scanner with a high resolution was used. By contrast, Pottier et al. and Niu et al. used the intraoral scanner Trios2 Color (3Shape Dental Systems, Copenhagen, Denmark). In general, industrial scanners provide a higher resolution than intraoral scanners. Although more accurate scans may be achieved and thus better results with the industrial scanner, it is important to establish a reliable scanning process that is practically applicable in a clinical patient setting.

Comparisons with data from Niu et al. and Pottier et al. on further possible influencing factors, such as slicing process or material or printers used, are limited as precise information is not available in the publications.[10,11]

Because additive manufacturing is layer by layer, the printer software has to break down the tray design into individual layers before printing. In this so-called slicing process, a layer thickness of 25–100 μm is usually selected. A smaller layer thickness provides a high-resolution object surface, which may enable a more exact setting of the bracket in the tray and thus improve the accuracy of bracket placement.[18] In the current study, a layer thickness of 50 μm was chosen. Pottier et al. and Niu et al., however, did not report on layer thickness for printing, on the material used for the three-dimensional printed trays, or on the type of DLP printer. However, as shown in the current study (Dreve vs NextDent), layer thickness and choice of the three-dimensional printed material had an influence on the accuracy of bracket placement (Figure 3), making a comparison of this study to results reported by Niu et al. and Pottier et al. difficult.

In the current study, PVS trays exceeded clinically acceptable limits the least frequently, followed by Dreve and NextDent (Figure 3). Regarding the rotation dimension, NextDent exceeded a clinically acceptable limit value of 1° significantly more often compared with PVS. Although this affected only one section of six dimensions investigated, NextDent appeared to be inferior to PVS. By contrast, Dreve exhibited similar results compared with PVS. Most likely, differences in the rate of exceeding the limit values were related to the material properties, as tray design and processes were identical. Underlining this assumption, it was noticed that the NextDent material had a much higher elasticity compared with Dreve and PVS. However, because the materials are new to the dental market and the manufacturer does not provide any information about the modulus of elasticity of the different materials, it was not possible to further substantiate that hypothesis.

The additional aim of the present study was to analyze the influence of the tooth groups on bracket transfer accuracy. Molars almost always exhibited the highest mean values of the transfer error regardless of the tray used (Table 2). However, Dreve only showed significantly higher values for molars in the buccolingual direction, whereas PVS trays exhibited significantly higher values for molars in all linear dimensions. A common explanation for higher transfer inaccuracies of molars is the difficulty in maintaining the same pressure on the entire tray during transfer, especially in the hard-to-reach posterior regions.[15,16] Following this argument, the same errors would be expected in all three trays. However, the transfer accuracy of Dreve trays were less influenced by the tooth groups. Based on this finding and in line with Niu et al., it may be assumed that the transfer error attributed to the influence of the different tooth groups may be reduced by an accurate three-dimensional printed tray (Dreve).

In general, the directional bias of the transfer error was evenly distributed for the different material groups (Table 3). However, an angular directional bias of up to 98.3% was observed for Dreve. In contrast to previous publications, an increased gingival shift was seen in this current study, probably attributed to excessive pressure on the tray during transfer. In addition, a lingual shift was found, probably caused by insufficient application of the luting material.

The high angular directional bias of up to 98.3% may be explained by the tray design. However, a similar bias was observed with the PVS trays, manufactured according to a standardized procedure independent of the three-dimensional printed trays. Therefore, it is more likely that angular directional bias was also caused by the transfer process.

CONCLUSIONS

- Three-dimensional printed trays achieved comparable results with the PVS trays in terms of bracket positioning accuracy.
- NextDent appears to be inferior compared with PVS regarding the frequency of clinically acceptable errors, whereas Dreve was found to be equal.
- The influence of tooth groups on the accuracy of bracket positioning may be reduced by using an appropriate three-dimensional printed transfer tray.

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