Accuracy of digital indirect bonding using different bracket transfer methods- an in vitro study

2022 Research Aid Awards (RAA)

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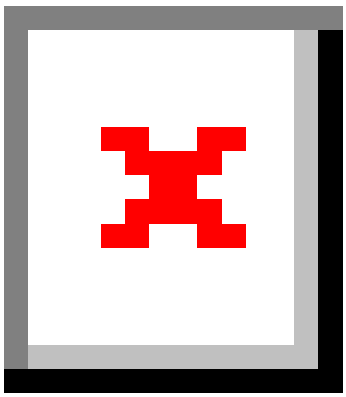

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Accuracy of digital indirect bonding using different bracket transfer methods- an in vitro study

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Research Aid Award (RAA)

Period of AAOF Support

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Institution

University of Illinois Chicago College of Dentistry

Names of principal advisor(s) / mentor(s), co-investigator(s) and consultant(s)

Dr. Sara Kahng (PI), Dr. Mohammed Elnagar(Co-I and Mentor), Dr. Budi Kusnoto(Co-I), Dr. Veerasathpurush Allareddy (Co-I)

Amount of Funding

$5,000.00

Abstract

(add specific directions for each type here)

A common challenge in orthodontics is accurate and efficient bracket placement. To resolve errors in bracket positioning, the indirect bonding technique was developed. Since its introduction, various methods have been developed to master the time-consuming technique. With the continued technological advances in orthodontics, current indirect bonding practices utilize intra-oral scanning, digital bracket placement software, and 3D printing. The aim of this study is to compare the transfer accuracy of digital indirect bonding techniques including flexible silicone trays, 3D printed resin trays, and vacuum formed trays using digitally bonded brackets and 3D printed models. The hypothesis of this study predicts there is no significant difference in transfer accuracy between the three methods of indirect bonding. The results of the proposed study will clarify which technique provides the greatest accuracy and will aid in streamlining the digital workflow of indirect bonding in clinical orthodontic practice. By mastering the indirect bonding technique, orthodontists will successfully reduce treatment time and costs and ultimately increase patient satisfaction.

Respond to the following questions:

Detailed results and inferences:*

If the work has been published, please attach a pdf of manuscript below by clicking "Upload a file".

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Use the text box below to describe in detail the results of your study. The intent is to share the knowledge you have generated with the AAOF and orthodontic community specifically and other who may benefit from your study. Table, Figures, Statistical Analysis, and interpretation of results should also be attached by clicking "Upload a file".

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Were the original, specific aims of the proposal realized?*

This study aimed to compare and assess the transfer accuracy of three digital indirect bonding techniques and materials: 3D printed resin bar, CAD driven silicone, and novel shape memory polymer (SMP) trays. Our objective was to 1) determine the most accurate bracket placement of the three techniques 2) determine which technique has the least amount of bracket bonding failures 3) provide a practical digital workflow for IDB techniques.

Our study results show that the bar tray design had the greatest frequency of error in bracket placement, followed by SMP, and silicone. In the linear direction (mesiodistal, occluso-gingival, and bucco-lingual) the bar transfer tray also had the greatest frequency of bracket transfer error followed by SMP, and silicone. Silicone trays had slightly lower overall incidence of bracket placement errors when compared to SMP. In all the angular dimensions (torque, rotation, and tip) all three techniques had significant errors. In terms of accuracy, SMP trays had the greatest overall accuracy particularly in the angular dimension followed by silicone and bar trays. In addition, SMP had the lowest rate of bracket failure compared to the other techniques. Regarding clinical acceptability, all the transfer techniques displayed clinical acceptability in the linear direction and all the techniques were not clinically acceptable in the angular dimension. Our results of clinical acceptability in the angular dimension challenge the findings of previous literature. However, our average angular errors would result in minimal clinical significance when considering wire-bracket play. Future investigation is needed to address transfer tray design to correct the angular placement errors and the appropriate range for clinical acceptability. In conclusion we reject our null hypotheses that there are no errors in bracket transfer position in the three IDB techniques: CAD driven silicone trays, 3D printed resin trays and shape-memory polymer trays and that there are no differences in transfer accuracy of the three IDB techniques: CAD driven silicone trays, 3D printed resin trays and shape-memory polymer. Our finding supports that SMP transfer trays displayed the greatest bracket placement accuracy compared to the other two techniques. While SMP has promising potential as novel material for IDB, further studies are needed to develop the SMP transfer tray for clinical IDB application.

Were the results published?*

No

Have the results of this proposal been presented?*

Yes

To what extent have you used, or how do you intend to use, AAOF funding to further your career?*

AAOF funding was essential to the completion and success of this study. All funding was used towards materials and supplies to conduct this research. With the support of AAOF funding I was able to contribute meaningful research to the field of orthodontics that will help me be a better clinician for my patients.

Accounting: Were there any leftover funds?

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Accuracy of Digital Indirect Bonding Using Different Bracket Transfer Methods and a Novel Tray Material- An In Vitro Study, Sara S. Kahng DDS, Budi Kusnoto DDS, MS, Veerasathpurush Allareddy BDS, PhD, Grace Viana BSc, MSc, and Mohammed H. Elnagar DDS, MS, PhD, AAO 2023 William R. Proffit Resident Scholar Award Presentation, Chicago IL

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Background

Since the introduction of the straight-wire technique by Andrews, ideal bracket positioning has been critical for efficient and excellent orthodontic results[1]. The IDB technique was developed by Silverman *et al*. to help overcome errors found in direct bonding (DB) procedures[2]. Common disadvantages found in DB include patient discomfort, obstructed view of patients' dentition, and mispositioned brackets[3]. IDB provides advantages of minimized patient discomfort, improved visualization of teeth, and reduction of wire bending from poor bracket positioning. Studies have shown IDB was more accurate for vertical bracket placement but no significant difference was found between accuracy of angulation and mesiodistal position between IDB and DB[4].

Conventionally, the IDB protocol involved physical impressions of the patient dentition, bracket placement onto stone models, and manual fabrication of the IDB transfer tray. For many clinicians, the traditional method was time-consuming and technique-sensitive resulting in the pursuit for a more practical approach. Non-digital IDB techniques vary in the materials used including silicone, vacuum-formed materials, and a combination of both[5]. When comparing the bracket transfer accuracy, studies have shown silicone based IDB techniques have superior accuracy[3,5,6].With the emergence of technology in orthodontics, digital IDB techniques have advanced. Intra-oral scanning, 3D printing, and IDB software are commonly incorporated in the digital workflow[7]. The IDB software allows for semi-automated bracket placement from a library of bracket types in addition to treatment outcome predicting features for improved bracket positioning[8,9].

Our study introduces the novel shape memory Tera Harz TC-85DAC resin, originally indicated for clear aligner therapy use, for IDB purposes[10,11]. The translucent, highly flexible, and shape memory properties make the TC-85DAC an appealing IDB transfer tray material. We seek to further evaluate the transfer accuracy of three different materials using a digital workflow.

Objectives

This study aims to compare and assess the transfer accuracy of three digital IDB techniques and materials: 3D printed resin, CAD driven silicone, and novel SMP trays. Our objective is to 1) determine the most accurate bracket placement of the three techniques 2) determine which technique has the least amount of bracket bonding failures 3) provide a practical digital workflow for IDB techniques.

Hypotheses

Based on our objectives, we have developed the following null hypotheses:

H_0: There are no errors in bracket transfer position in the three IDB techniques: 3D printed resin trays, CAD driven silicone trays, and shape-memory polymer trays.

H_a: There are errors in bracket transfer position in the three IDB techniques: 3D printed resin trays, CAD driven silicone trays, and shape-memory polymer trays.

H_0: There are no differences in transfer accuracy of the three IDB techniques: 3D printed resin trays, CAD driven silicone trays, and shape-memory polymer trays.
H_a: There are differences in transfer accuracy of the three IDB techniques: 3D printed resin trays, CAD driven silicone trays, and shape-memory polymer trays.

Methods

The objective of this study is to evaluate the bracket transfer accuracy of three distinct digital IDB techniques: 3D printed resin, CAD driven silicone, and 3D printed shape-memory polymer (SMP) trays. 15 maxillary and 15 mandibular intra-orally scanned arches of pre-existing University of Illinois Chicago (UIC) Orthodontic Department were used for the study. Brackets were semi-automatically placed on each arch following the digitally fabricated facial axis (FA) point. 30 IDB transfer trays were produced for each material: 3D printed resin ("bar"), CAD driven silicone ("silicone"), and 3D printed ("SMP") for a total of 90 transfer trays. IDB was performed for each technique and bracketed models were scanned for superimposition to test accuracy in the linear (mesiodistal, occluso-gingival, and bucco-lingual) and angular (torque, rotation, and tip) dimensions. A one-sample t-test was conducted to assess for any significant error in bracket placement in the three materials. A repeated measures ANOVA, with Greenhouse-Geisser correction, was conducted to assess whether there were mean differences between the three techniques in the linear and angular dimension.

Results

Bracket failure

A total of 68 brackets failed upon removal of the transfer trays during the IDB procedures. 36 brackets failed from the bar technique, 24 from the silicone, and 8 from the SMP tray (Table 1). Debonded brackets were not included in the final analysis. An additional 31 brackets were not included in the evaluation due to inability to seat brackets in the transfer tray, software error, or scanning error. In total, 1,161 brackets were examined- 381 in the bar method, 391 in the silicone method, and 389 in the SMP method.

Table 1: Frequency of bracket failures for each technique

Technique	**Frequency of Bracket Failure n (%)**
Bar	36 (9%)
Silicone	24 (6%)
SMP	8 (2%)

Frequency of bracket transfer error (linear)

When examining the accuracy of bracket placement in both the linear and angular measurements at test value equals 0, the bar method had the greatest percentage of statistically significant error in bracket placement (81%) followed by SMP (75%) then silicone (73%) (Table 2). Bar had the greatest prevalence of statistically significant errors in the linear measurements (mesiodistal, occluso-gingival, and bucco-lingual) at 64%, followed by SMP 51%, and silicone 44% (Table 3). For molars, bar had the greatest prevalance of statistically significant errors in the linear measurements (67%) followed by SMP (54%), then silicone (25%). For premolars, bar had the greatest error (83%), followed by silicone (63%), then SMP (54%). For canines, bar had the greatest significant error (58%) followed by silicone (52%) and then SMP (33%). Lastly, for incisors, SMP had the greatest errors (54%) followed by silicone (46%) then bar (42%) (Table 4). When categorizing significant error in bracket placement by directional variables in the linear measurements, mesiodistally, bar had the greatest frequency of error (68%) followed by SMP (39%) and silicone (32%). In the occluso-gingival, bar had the greatest prevalence of error (57%) followed by silicone (50%), and SMP (46%). Lastly, in the bucco-lingual direction, bar had the greatest frequency of significant error (68%) followed by SMP (67%), and silicone (50%) (Table 5).

Table 2: Prevalence of significant error in brackekt placement in both linear and angular directions for all three techniques.

Technique	**Frequency of Error n (%)**
Bar	136 (81%)
Silicone	122 (73%)
SMP	126 (75%)

Table 3: Prevalence of significant error in bracket placement in the linear or angular direction for all three techniques.

	Bar		Silicone		SMP	
	Linear n (%)	Angular n (%)	Linear n (%)	Angular n (%)	Linear n (%)	Angular n (%)
Incisors	10 (42%)	24 (100%)	11 (46%)	24 (100%)	13 (54%)	24 (100%)
Canines	7 (58%)	12 (100%)	5 (52%)	12 (100%)	4 (33%)	12 (100%)
Premolars	20 (83%)	24 (100%)	15(63%)	24 (100%)	13 (54%)	24 (100%)
Molars	16 (67%)	24 (100%)	6 (25%)	24 (100%)	13 (54%)	24 (100%)

Table 4: Prevalence of significant error in bracket placement the linear and angular direction for groups of teeth (incisors, canines , premolars, and molar) for all three techniques.

	Measurement n (%)	
Technique	Linear	Angular
Bar	54 (64%)	84 (100%)
Silicone	37 (44%)	84 (100%)
SMP	43 (51%)	84 (100%)

Table 5: Prevalence of significant error in bracket placement in linear (mesiodistal, occluso-gingival, bucco-lingual) and angular (torque, rotation, tip) for all teeth in all three techniques.

	Bar n (%)	**Silicone n (%)**	**SMP n (%)**
Mesiodistal	19 (68%)	9 (32%)	11 (39%)
Occluso-gingival	16 (57%)	14 (50%)	13 (46%)
Bucco-lingual	19 (68%)	14 (50%)	19 (67%)
Torque	28 (100%)	28 (100%)	28 (100%)
Rotation	28 (100%)	28 (100%)	28 (100%)
Tip	28 (100%)	28 (100%)	28 (100%)

Frequency of bracket transfer error (angular)

In regards to the angular measurements (torque, rotation, and tip) all methods had 100% statistically significant error for bracket placement for every tooth (Table 3, Table 4, and Table 5).

Difference of transfer error between techniques (incisors)

In the linear measurements for incisors, there was no significant difference between the three techniques in the mesiodistal and occluso-gingival direction. There was a significant difference in the bucco-lingual direction with bar (0.093 ± 0.086) and silicone (0.121 ± 0.066) being more accurate than SMP (0.212 ± 0.106) (Table 6).

In the angular measurements for incisors there was a significant difference in torque with silicone (4.139 ± 1.196) and SMP (4.027 ± 1.553) being more accurate than bar (6.563 ± 1.212). There was a significant difference in rotation with SMP (2.755 ± 1.096) being more accurate than bar (3.946 ± 1.157) and silicone (4.988 ± 1.323). There was a significant difference in tip with SMP (3.871 ± 1.236) and silicone (4.043 ± 1.324) being more accurate than bar (5.944 ± 1.334) (Table 6).

Overall, in the linear measurements for the incisors, the bar method was more accurate than SMP and silicone in the bucco-lingual direction. In the angular dimensions, the SMP technique was more accurate than silicone and bar in torque, rotation, and tip (Table 6).

Table 6: Mean, standard deviations, and significance of mean differences between the three techniques in linear (mesiodistal, occlusal-gingival, bucco-lingual) and angular (torque, rotation, tip) directions following Student's paired t- test for incisors.

	Incisors						
	Bar (T1)	**Silicone (T2)**	**SMP (T3)**	**p-value**	**T1-T2**	**T1-T3**	**T2-T3**
	n=15	n=15	n=15				
Mesiodistal	-0.004 ± 0.048	0.003 ± 0.044	0.025 ± 0.035	NS			
Occluso-gingival	-0.068 ± 0.200	-0.159 ± 0.098	-0.157 ± 0.194	NS			
Bucco-lingual	0.093 ± 0.086	0.121 ± 0.066	0.212 ± 0.106	0.001		0.008	0.006
Torque	6.563 ± 1.212	4.139 ± 1.196	4.027 ± 1.553	<0.001	<0.001	<0.001	
Rotation	3.946 ± 1.157	4.988 ± 1.323	2.755 ± 1.096	<0.001		0.015	<0.001
Tip	5.944 ± 1.334	4.043 ± 1.324	3.871 ± 1.236	<0.001	<0.001	0.001	

Difference of transfer error between techniques (canines)

In the linear measurement for the canines, there was no significant difference between the three techniques in the bucco-lingual and occluso-gingival directions. There was a significant difference in the mesiodistal direction with silicone (0.045 ± 0.089) being more accurate than SMP (0.132 ± 0.088) (Table 7).

In the angular measurements for the canines, there was no significant difference between the three techniques in tip and torque. There was a significant difference in rotation with SMP (3.791 ± 0.866) being more accurate than silicone (5.597 ± 1.676) and bar (4.239 ± 1.212) being more accurate than silicone (Table 7).

Overall, in the linear measurements for the canines, the silicone technique was more accurate than SMP and bar in the mesiodistal direction. In the angular dimensions, the SMP method was more accurate than silicone and bar in rotation (Table 7).

Table 7: Mean, standard deviations, and significance of mean differences between the three techniques in linear (mesiodistal, occlusal-gingival, bucco-lingual) and angular (torque, rotation, tip) directions following Student's paired t-test for canines.

	Canines						
	Bar (T1)	**Silicone (T2)**	**SMP (T3)**	**p-value**	**T1-T2**	**T1-T3**	**T2-T3**
	n=15	n=15	n=15				
Mesiodistal	0.097 ± 0.088	0.045 ± 0.089	0.132 ± 0.088	0.043			0.003
Occluso-gingival	-0.011 ± 0.235	-0.028 ± 0.109	0.034 ± 0.133	NS			
Bucco-lingual	-0.024 ± 0.056	-0.045 ± 0.075	-0.002 ± 0.064	NS			
Torque	5.669 ± 1.812	5.347 ± 1.130	4.732 ± 1.559	NS			
Rotation	4.239 ± 1.212	5.597 ± 1.676	3.791 ± 0.866	<0.001	0.003		<0.001
Tip	5.835 ± 1.862	5.876 ± 1.330	4.619 ± 1.751	NS			

Difference of transfer error between techniques (premolars)

In the linear measurements for premolars, there was no significant difference between the three techniques in the bucco-lingual direction. There was a significant difference in the occluso-gingival direction with bar (-0.097 ± 0.120) being more accurate than SMP (0.125 ± 0.151) and silicone (-0.158 ± 0.109). There was a significant difference in the mesiodistal direction with SMP (0.001 ± 0.075) being more accurate than bar (0.111 ± 0.057) and silicone (0.138 ± 0.069) (Table 8).

In the angular measurements for premolars there was no significant difference between the three techniques in rotation and tip. There was a significant difference in torque with SMP (3.606 ± 0.726) being more accurate than both silicone (5.361 ± 1.244) and bar (5.007 ± 0.980) (Table 8).

Overall, in the linear measurement for premolars, the SMP technique was more accurate than bar and silicone in the mesiodistal direction and the bar method was more accurate in the occluso-gingival direction. In the angular dimensions, the SMP method was more accurate than the bar and silicone in torque (Table 8).

Table 8: Mean, standard deviations, and significance of mean differences between the three techniques in linear (mesiodistal, occlusal-gingival, bucco-lingual) and angular (torque, rotation, tip) directions following Student's paired t-test for premolars.

	Premolars						
	Bar (T1)	**Silicone (T2)**	**SMP (T3)**	**p-value**	**T1-T2**	**T1-T3**	**T2-T3**
	n=15	n=15	n=15				
Mesiodistal	0.111 ± 0.057	0.138 ± 0.069	0.001 ± 0.075	<0.001		<0.001	<0.001
Occluso-gingival	-0.097 ± 0.120	-0.158 ± 0.109	0.125 ± 0.151	<0.001		<0.001	<0.001
Bucco-lingual	0.032 ± 0.046	0.000 ± 0.045	0.040 ± 0.048	NS			
Torque	5.007 ± 0.980	5.361 ± 1.244	3.606 ± 0.726	<0.001		<0.001	<0.001
Rotation	4.330 ± 0.838	4.685 ± 1.083	4.621 ± 1.187	NS			
Tip	5.032 ± 0.899	4.801 ± 1.242	4.534 ± 1.324	NS			

Difference of transfer error between techniques (molars)

In the linear measurements for molars, there was no significant difference between the three techniques in the occluso-gingival and bucco-lingual direction. There was a significant difference in the mesiodistal direction with SMP (-0.027 ± 0.171) being more accurate than both silicone (0.100 ± 0.104) and bar (0.263 ± 0.230) (Table 9).

In the angular measurements for molars, there was no significant difference between the three techniques in tip and torque. There was a significant difference in rotation with SMP (4.880 ± 1.275) being more accurate than silicone (6.473 ± 1.677) and bar (5.601 ± 1.949) (Table 9). Overall, in the linear dimension, the SMP method was more accurate than silicone and bar in the mesiodistal direction. In the angular measurements, the SMP technique was more accurate than silicone and bar in rotation (Table 9).

Table 9: Mean, standard deviations, and significance of mean differences between the three techniques in linear (mesiodistal, occlusal-gingival, bucco-lingual) and angular (torque, rotation, tip) directions following Student's paired t-test for molars.

	Molars						
	Bar (T1)	**Silicone (T2)**	**SMP (T3)**	**p-value**	**T1-T2**	**T1-T3**	**T2-T3**
	n=15	n=15	n=15				
Mesiodistal	0.263 ± 0.230	0.100 ± 0.104	-0.027 ± 0.171	<0.001	0.022	0.003	0.026
Occluso-gingival	-0.001 ± 0.207	0.100 ± 0.101	-0.148 ± 0.439	NS			
Bucco-lingual	0.020 ± 0.077	-0.029 ± 0.063	-0.021 ± 0.121	NS			
Torque	5.850 ± 2.114	5.995 ± 1.241	4.861 ± 1.776	NS			
Rotation	5.601 ± 1.949	6.473 ± 1.677	4.880 ± 1.275	<0.001	0.047	0.036	0.001
Tip	5.863 ± 1.720	4.924 ± 1.603	5.427 ± 1.583	NS			

Clinical Acceptability

This study found all three methods yielded 100% clinical acceptability of placement errors in the linear measurements (all values were <0.5mm) and 0% clinical acceptability in the angular measurements (all values were >2°) (Table 10).

Table 10: Prevalence of clinical acceptability of linear (mesiodistal, occluso-gingival, bucco-lingual) <0.5 mm and angular (torque, rotation, tip) <2° deviation for all teeth in all three techniques.

	Bar	**Silicone**	**SMP**
Mesiodistal	100%	100%	100%
Occluso-gingival	100%	100%	100%
Bucco-lingual	100%	100%	100%
Torque	0%	0%	0%
Rotation	0%	0%	0%
Tip	0%	0%	0%

Discussion

The purpose of our study was to compare three different digital IDB techniques to determine which method and material had the greatest transfer accuracy. Currently, the most common materials used for digital IDB are silicone-based or vacuum-formed materials on a 3D printed transfer model and 3D printed transfer trays[8,12]. Previous literature states silicone-based transfer trays has the highest accuracy due to its dimensional stability, elasticity, and transparent properties[13]. For this reason, the CAD driven silicone transfer trays was used as our reference point. 3D printed transfer trays were also included in the study due to having similar transfer accuracy to silicone-based trays[13]. The last method in our study used a novel SMP material which has comparable elastic properties of silicone and the time-saving advantage of 3D printed trays[10,12].

With the emergence of advancing technology, methods to objectively evaluate transfer accuracy have improved. Previous literature was limited to 2D measurements using digital photography and unreliably determined bracket position error based on operator eyesight[5,14]. Similar to recent studies, our current study used a more objective method to analyze bracket placement error by 3D superimposition of the control and experimental models[12,15]. The superimposition was based upon tooth surfaces rather than bracket structures thus ensuring a more accurate superimposition[16]. This objective method offers more exact measurements and can calculate values under 0.1 mm or 0.1°[15].

This study defined bracket failure as a bracket debonding during transfer tray removal. The 3D printed resin transfer tray had the greatest number of bracket failures (36) followed by silicone (24) and the SMP (8). A total of 68 failed brackets resulted in a failure rate of 5.3% which is higher than reported in previous literature[13]. Higher bracket failure found in 3D printed resin tray was likely due to the stiffness of the tray and over-retentive features within the bracket well. Similarly, less bracket failures found in silicone and SMP trays was likely due to the trays' flexible properties making it easier to peel the transfer tray away from the bonded brackets. Careful consideration is required when digitally designing the IDB tray as the bracket well must precisely match the dimensions of the bracket to ensure accurate bracket transfer[12]. Retentive features are necessary to prevent bracket displacement upon bracket loading and tray handling. However, if the tray is too retentive, brackets cannot be easily released from the tray during the IDB procedure[12].

Many studies only examined IDB accuracy from premolar to premolar of a singular arch. This study included brackets from second molar to second molar of both maxillary and mandibular arches to obtain a more extensive analysis. Linear and angular deviations found in molar tubes are likely due to the different shape compared to brackets. Unlike angular brackets with many areas of undercuts, the cylindrical molar tubes are rounded with undefined edges resulting in a lack of possible retentive areas when designing the transfer trays[16]. As a result, molar tubes may not have been securely seated in the trays despite proper transfer tray design and were displaced upon tray handling during the IDB procedure. In addition, scanning errors may contribute to an inaccurate deviation calculation. Despite using a mattifying intra-oral spray on the bracketed models, the reflectiveness of the molar tubes and brackets made it difficult to obtain a complete scan of the bracketed models for the superimposition[17]. For brackets and molar tubes with incomplete scans, the correct surfaces needed for the three planes to make a 3D coordinate were unclear. Therefore, the operator had to make a best-guess judgment when selecting the plane surface. This imprecise method could lead to errors in the linear and angular deviation calculations.

Higher frequency of transfer errors in the linear measurements were found in the bar technique compared to the silicone and SMP method. Specifically, premolars in the bar technique had the highest frequency of placement error. These results indicate that the 3D printed resin material may be too stiff and proper loading of brackets into the bracket well was not accurate or that the transfer tray did not seat fully upon the patient model. However, for all techniques the average linear measurement error for all teeth was between 0.000 ± 0.061 and 0.486 ± 0.741mm and were all within the clinically acceptable range. Less frequency of error found in the silicone and SMP methods are attributed to the flexible properties of both materials and reflects similar findings of previous studies[16].

In our study, our average depth error ranged from 0.000 ± 0.045 to 0.212 ± 0.016mm. This range is higher than previous studies that used hard CAD/CAM trays sectioned at each tooth which reported depth error from 0.07 to 0.11mm[15,18]. Our depth values more closely aligned with the findings of Yoo *et al*. which reported depth error range from 0.12 to 0.26 mm[17]. Yoo *et al*. found lower depth error value in transfer trays that used marker 3D printed transfer models because the brackets were already adapted to the tooth surface during fabrication of the transfer tray[17]. Our study challenged these findings as our bar technique which was a directly 3D printed tray, had greater depth accuracy than our marker model derived silicone trays.

Previous studies have shown high depth errors in premolars[14,17]. However, in our study, incisors had the greatest depth error specifically in the SMP technique. This could be a result of operator error of seating the transfer tray first from second molar to second molar and not adapting the incisor portion of the tray close enough to the model. Another consideration is that the SMP is stiff when not submerged in hot water. When seating the SMP tray on the model in its cool state, the stiffness of the SMP could prevent the brackets from fully adapting to the tooth surface on the incisors.

In a study by Duarte *et al*. tip error was found between 0.18 to 4.15° which was determined by superimposing the long axis of the original virtual bracketed model to the scanned model after indirect bonding[19]. These findings follow another study, in which the tip error was measured between 0.96 to 5.37°[17]. The bracket positioning error was determined by merging the reverse-engineered bracket library with measured model may reduce scanning inaccuracies[17]. In our study the average tip error ranged from 3.871 ± 1.236 to 5.944 ± 1.334° with the lower range being higher than previous studies. In addition, torque errors in previous studies were observed at 1.99-3.36°[15,18]. These findings challenged our results in which the torque errors were between 3.606 ± 0.726 and 6.563 ± 1.212° with the SMP having the greatest accuracy. Many previous studies have used the ABO standard of <0.5mm and <2° for determining clinical acceptability[13,20]. However depending on the size of the teeth and wire-bracket play, the relationship between tip and marginal ridge discrepancy differs. For example, according to Yoo et. al, a tip error of 6.7° could result in a 0.5mm marginal ridge discrepancy if the tooth width was 8mm[17]. Further studies are needed to determine the appropriate clinical cutoff for linear and angular errors[17].

In contrast to previous literature, our study found significant placement error in all angular dimensions (torque, rotation, and tip) for all techniques[13, 16]. In addition, all angular dimensions were above the clinical acceptability limit of <2°. This discrepancy could be attributed to the transfer tray design and further retentive features are required in the tray to prevent torque, rotational, and tip errors. While our average angular deviation ranged from 2.025 ± 2.290 to 8.284 ± 4.213°, any clinical consequences of these angular errors would not express until a heavy wire is engaged in the bracket slot. When considering wire-bracket play, torque deviations would have little influence on the final alignment. According to Yoo *et al*. placing a 0.19 × 0.25-in wire in a 0.22 slot results in 7.24° wire-bracket play[17].

Although the angular errors in our study was higher than what was reported in previous literature, we applied a more robust method for assessment. First, our study utilized 3D coordinates derived from manually determined intersecting planes. Compared to other studies where coordinates were taken from a center point of the bracket or studies that used 2D analysis, our method ensured a more precise and accurate measurement. In addition, our study sample consisted of models of real patients with various amount of crowding and spacing. Including variation of patient types rather than a standard typodont model like previous studies could yield higher deviations in the angular measurements. Furthermore, our study included molar teeth of both upper and lower arches compared to earlier studies that limited their study to single arches premolar to premolar. These additional considerations in our study may contribute to the higher angular deviations that were reported.

For individual groups of teeth, SMP displayed the greatest accuracy specifically in the angular directions for incisors and canines and in both linear and angular dimensions for premolars and molars. The greater accuracy can be attributed to the flexible property of SMP when heated and the stiffness that is regained at cooler temperature. When the SMP tray is heated and brackets are seated in the tray, the bracket is stabilized in its position as the tray cools and regains its stiffness resulting in a more accurate placement during the IDB transfer. Based on our results, we reject our null hypotheses and accept our alternative hypotheses. SMP had greater accuracy compared to the other two techniques and less bracket failures. The shape memory property gives the SMP transfer trays the necessary flexibility to load brackets accurately and to remove to the tray with minimal bracket failure. In addition, silicone trays had the lowest frequency of bracket placement error. SMP showed promising results toward being a key player in IDB tray fabrication.

Practical clinical implication of digital IDB

There is a growing popularity of digital IDB over non-digital IDB in orthodontic offices. Layman *et al* reports the digital IDB workflow saves a total of 21 minutes of lab time per patient compared to non-digital methods, and an additional 8 minutes of chair time compared to direct bonding[7]. The author recognizes the benefits of digital IDB is multifold as it increases office efficiency by improving the daily clinical workflow and minimizes the need for repositioning of brackets and bending of wires. Furthermore, there are more options available to providers to outsource the fabrication of IDB trays[7].

Hurdles to implementing digital IDB in the office

There are some limitations of digital IDB that make its implementation in orthodontic practices difficult. Many offices do not use digital IDB due to[21]:

1. Increased laboratory time
2. Learning curve to understand how to use IDB software
3. Resistance of staff to change of the conventional DB workflow
4. Cost of equipment (intra-oral scanner, 3D printer, IDB software, lab costs)

Integration of SMP trays in practices would require specific post-processing equipment which would incur further costs. Furthermore, same-day starts are not possible with IDB which is not ideal from a practice management standpoint. While anecdotally providers, who have incorporated digital IDB in their practice, report reduced treatment duration due to less bracket repositioning and arch wire bends, objective evidence is needed to validate these claims.

Conclusion

Our study results show that the bar tray design had the greatest frequency of error in bracket placement, followed by SMP, and silicone. In the linear direction (mesiodistal, occluso-gingival, and bucco-lingual) the bar transfer tray also had the greatest frequency of bracket transfer error followed by SMP, and silicone. Silicone trays had slightly lower overall incidence of bracket placement errors when compared to SMP. In all the angular dimensions (torque, rotation, and tip) all three techniques had significant errors.

In terms of accuracy, SMP trays had the greatest overall accuracy particularly in the angular dimension followed by silicone and bar trays. In addition, SMP had the lowest rate of bracket failure compared to the other techniques.

Regarding clinical acceptability, all the transfer techniques displayed clinical acceptability in the linear direction and all the techniques were not clinically acceptable in the angular dimension. Our results of clinical acceptability in the angular dimension challenge the findings of previous literature. However, our average angular errors would result in minimal clinical significance when considering wire-bracket play. Future investigation is needed to address transfer tray design to correct the angular placement errors and the appropriate range for clinical acceptability.

In conclusion we reject our null hypotheses that there are no errors in bracket transfer position in the three IDB techniques: CAD driven silicone trays, 3D printed resin trays and shape-memory polymer trays and that there are no differences in transfer accuracy of the three IDB techniques: CAD driven silicone trays, 3D printed resin trays and shape-memory polymer. Our finding supports that SMP transfer trays displayed the greatest bracket placement accuracy compared to the other two techniques. While SMP has promising potential as novel material for IDB, further studies are needed to develop the SMP transfer tray for clinical IDB application.

Appendix Figures

Appendix A.1 Table of mean and standard deviation of placement error of upper right quadrant following a one-sample t-test with test value equals 0

	UR1					
	Bar n=13	***p*** **value**	**Silicone** n=13	***p*** **value**	**SMP** n=15	***p*** **value**
Mesiodistal (mm)	0.073 ± 0.159	0.126	0.058 ± 0.118	0.100	-0.029 ± 0.105	0.308
Occluso-gingival (mm)	-0.276 ± 0.393	0.026	-0.055 ± 0.248	0.439	-0.458 ± 0.279	<.001
Bucco-lingual (mm)	0.183 ± 0.136	<.001	0.198 ± 0.144	<.001	0.360 ± 0.150	<.001
Torque (degrees)	4.575 ± 2.852	<.001	4.160 ± 2.275	<.001	2.657 ± 1.868	<.001
Rotation (degrees)	4.815 ± 3.108	<.001	5.866 ± 2.746	<.001	2.342 ± 1.177	<.001
Tip (degrees)	6.164 ± 2.587	<.001	4.762 ± 2.748	<.001	2.784 ± 1.710	<.001

	UR2						UR3					
	Bar n=12	***p*** **value**	**Silicone** n=14	***p*** **value**	**SMP** n=13	***p*** **value**	**Bar** n=12	***p*** **value**	**Silicone** n=14	***p*** **value**	**SMP** n=14	***p*** **value**
Mesiodistal (mm)	0.156 ± 0.167	0.008	0.020 ± 0.143	0.617	0.035 ± 0.117	0.306	0.123 ± 0.125	0.006	0.042 ± 0.214	0.476	0.149 ± 0.131	<.001
Occluso-gingival (mm)	-0.169 ± 0.417	0.188	-0.021 ± 0.204	0.700	-0.357 ± 0.299	0.001	0.013 ± 0.310	0.890	-0.184 ± 0.359	0.077	-0.097 ± 0.339	0.304
Bucco-lingual (mm)	0.097 ± 0.106	0.009	0.052 ± 0.123	0.135	0.241 ± 0.141	<.001	0.059 ± 0.066	0.010	0.024 ± 0.195	0.647	-0.076 ± 0.190	0.158
Torque (degrees)	7.757 ± 4.058	<.001	5.058 ± 1.543	<.001	5.347 ± 2.435	<.001	6.239 ± 2.677	<.001	5.298 ± 1.594	<.001	4.311 ± 3.316	<.001
Rotation (degrees)	3.275 ± 2.389	<.001	5.927 ± 2.472	<.001	3.603 ± 1.722	<.001	4.275 ± 2.136	<.001	6.021 ± 2.143	<.001	3.267 ± 1.725	<.001
Tip (degrees)	6.792 ± 4.251	<.001	4.291 ± 2.549	<.001	4.877 ± 2.893	<.001	5.873 ± 2.979	<.001	6.113 ± 1.832	<.001	4.850 ± 3.308	<.001

	UR4						UR5					
	Bar n=13	***p*** **value**	**Silicone** n=15	***p*** **value**	**SMP** n=15	***p*** **value**	**Bar** n=13	***p*** **value**	**Silicone** n=15	***p*** **value**	**SMP** n=14	***p*** **value**
Mesiodistal (mm)	0.056 ± 0.049	0.001	0.082 ± 0.104	0.008	-0.022 ± 0.099	0.400	0.037 ± 0.126	0.312	0.077 ± 0.083	0.003	-0.088 ± 0.087	0.002
Occluso-gingival (mm)	0.164 ± 0.245	0.032	-0.107 ± 0.284	0.168	0.079 ± 0.303	0.332	0.246 ± 0.239	0.003	0.000 ± 0.248	0.998	0.212 ± 0.336	0.034
Bucco-lingual (mm)	0.118 ± 0.103	0.001	0.044 ± 0.130	0.214	-0.103 ± 0.162	0.027	0.144 ± 0.134	0.002	0.017 ± 0.185	0.726	-0.118 ± 0.241	0.091
Torque (degrees)	3.725 ± 1.498	<.001	3.045 ± 1.011	<.001	3.028 ± 1.915	<.001	6.591 ± 2.697	<.001	3.878 ± 1.952	<.001	2.948 ± 2.118	<.001
Rotation (degrees)	3.578 ± 1.417	<.001	3.948 ± 2.034	<.001	3.019 ± 1.733	<.001	5.310 ± 2.287	<.001	4.053 ± 2.177	<.001	3.525 ± 2.071	<.001
Tip (degrees)	4.111 ± 1.634	<.001	3.898 ± 2.078	<.001	3.568 ± 1.977	<.001	5.698 ± 2.487	<.001	3.675 ± 1.789	<.001	3.821 ± 2.334	<.001

	UR6						UR7					
	Bar n=13	***p*** **value**	**Silicone** n=15	***p*** **value**	**SMP** n=15	***p*** **value**	**Bar** n=15	***p*** **value**	**Silicone** n=13	***p*** **value**	**SMP** n=13	***p*** **value**
Mesiodistal (mm)	0.426 ± 0.446	0.005	0.170 ± 0.212	0.008	-0.101 ± 0.254	0.147	0.193 ± 0.399	0.083	0.180 ± 0.365	0.100	-0.166 ± 0.129	<.001
Occluso-gingival (mm)	-0.178 ± 0.418	0.151	0.211 ± 0.143	<.001	-0.249 ± 0.437	0.045	-0.339 ± 0.303	<.001	0.087 ± 0.231	0.197	-0.346 ± 0.415	0.011
Bucco-lingual (mm)	-0.095 ± 0.118	0.013	-0.111 ± 0.220	0.071	-0.226 ± 0.202	<.001	0.031 ± 0.211	0.582	0.005 ± 0.382	0.961	-0.213 ± 0.311	0.030
Torque (degrees)	6.676 ± 6.570	0.003	5.918 ± 3.283	<.001	4.821 ± 2.726	<.001	5.634 ± 2.439	<.001	4.052 ± 2.686	<.001	5.061 ± 3.244	<.001
Rotation (degrees)	5.848 ± 5.692	0.003	6.799 ± 2.942	<.001	4.436 ± 2.248	<.001	6.132 ± 3.610	<.001	5.177 ± 3.683	<.001	5.510 ± 1.961	<.001
Tip (degrees)	6.747 ± 4.432	<.001	5.656 ± 2.231	<.001	2.903 ± 2.539	<.001	5.798 ± 3.731	<.001	4.884 ± 3.492	<.001	6.160 ± 3.050	<.001

Appendix A.2 Table of mean and standard deviation of placement error of upper left quadrant following a one-sample t-test with test value equals 0

	UL1					
	Bar n=11	***p* value**	**Silicone** n=14	***p* value**	**SMP** n=15	***p* value**
Mesiodistal (mm)	-0.023 ± 0.157	0.631	0.000 ± 0.061	0.999	0.091 ± 0.138	0.023
Occluso-gingival (mm)	-0.007 ± 0.407	0.955	0.065 ± 0.157	0.147	-0.415 ± 0.381	<.001
Bucco-lingual (mm)	0.108 ± 0.172	0.064	0.141 ± 0.127	0.001	0.292 ± 0.170	<.001
Torque (degrees)	6.343 ± 2.904	<.001	4.972 ± 2.195	<.001	3.131 ± 2.271	<.001
Rotation (degrees)	3.410 ± 1.676	<.001	5.454 ± 2.271	<.001	2.025 ± 2.290	0.004
Tip (degrees)	5.318 ± 3.384	<.001	3.312 ± 2.256	<.001	2.481 ± 1.470	<.001

	UL2						UL3					
	Bar n=14	***p* value**	**Silicone** n=15	***p* value**	**SMP** n=15	***p* value**	**Bar** n=12	***p* value**	**Silicone** n=15	***p* value**	**SMP** n=15	***p* value**
Mesiodistal (mm)	-0.102 ± 0.118	0.007	0.014 ± 0.080	0.509	0.019 ± 0.136	0.605	0.191 ± 0.183	0.004	0.099 ± 0.159	0.031	0.215 ± 0.174	<.001
Occluso-gingival (mm)	0.226 ± 0.423	0.067	0.029 ± 0.122	0.379	-0.010 ± 0.328	0.905	0.245 ± 0.352	0.035	0.177 ± 0.165	<.001	0.003 ± 0.285	0.972
Bucco-lingual (mm)	0.041 ± 0.143	0.297	0.100 ± 0.134	0.012	0.209 ± 0.162	<.001	-0.096 ± 0.108	0.011	-0.100 ± 0.127	0.009	0.066 ± 0.201	0.221
Torque (degrees)	7.435 ± 2.936	<.001	3.945 ± 2.020	<.001	5.761 ± 3.818	<.001	6.915 ± 4.317	<.001	8.284 ± 4.213	<.001	6.149 ± 3.642	<.001
Rotation (degrees)	3.362 ± 2.280	<.001	4.340 ± 2.699	<.001	3.346 ± 2.370	<.001	5.826 ± 4.551	0.001	6.873 ± 3.373	<.001	5.094 ± 1.896	<.001
Tip (degrees)	6.990 ± 2.814	<.001	3.971 ± 2.624	<.001	5.476 ± 3.359	<.001	7.806 ± 4.332	<.001	7.814 ± 3.060	<.001	6.447 ± 2.833	<.001

	UL4						UL5					
	Bar n=15	***p* value**	**Silicone** n=15	***p* value**	**SMP** n=15	***p* value**	**Bar** n=15	***p* value**	**Silicone** n=15	***p* value**	**SMP** n=15	***p* value**
Mesiodistal (mm)	0.140 ± 0.150	0.003	0.149 ± 0.117	<.001	-0.005 ± 0.091	0.822	0.056 ± 0.090	0.029	0.089 ± 0.194	0.097	-0.076 ± 0.089	0.005
Occluso-gingival (mm)	0.084 ± 0.329	0.338	-0.070 ± 0.267	0.328	0.093 ± 0.285	0.229	0.200 ± 0.243	0.007	-0.089 ± 0.363	0.36	0.017 ± 0.432	0.883
Bucco-lingual (mm)	0.003 ± 0.095	0.908	-0.001 ± 0.132	0.976	0.274 ± 0.191	<.001	0.036 ± 0.093	0.157	-0.055 ± 0.211	0.33	0.270 ± 0.232	<.001
Torque (degrees)	5.088 ± 2.703	<.001	6.907 ± 3.777	<.001	2.294 ± 1.642	<.001	4.546 ± 2.679	<.001	5.857 ± 3.361	<.001	3.515 ± 1.420	<.001
Rotation (degrees)	3.998 ± 2.626	<.001	5.398 ± 3.905	<.001	3.150 ± 1.675	<.001	4.030 ± 2.166	<.001	5.514 ± 3.508	<.001	2.671 ± 1.231	<.001
Tip (degrees)	4.489 ± 2.789	<.001	5.262 ± 3.192	<.001	2.708 ± 1.420	<.001	4.305 ± 2.815	<.001	5.075 ± 3.118	<.001	3.638 ± 1.313	<.001

	UL6						UL7					
	Bar n= 13	***p* value**	**Silicone** n=14	***p* value**	**SMP** n=14	***p* value**	**Bar** n=14	***p* value**	**Silicone** n=14	***p* value**	**SMP** n=14	***p* value**
Mesiodistal (mm)	0.287 ± 0.258	0.002	0.096 ± 0.294	0.243	0.046 ± 0.259	0.52	0.290 ± 0.248	<.001	0.036 ± 0.213	0.535	-0.159 ± 0.194	0.009
Occluso-gingival (mm)	-0.223 ± 0.264	0.01	0.133 ± 0.212	0.035	-0.251 ± 0.340	0.016	-0.314 ± 0.258	<.001	0.016 ± 0.306	0.844	-0.481 ± 0.388	<.001
Bucco-lingual (mm)	-0.014 ± 0.182	0.79	0.067 ± 0.265	0.362	0.296 ± 0.333	0.006	-0.037 ± 0.149	0.371	0.065 ± 0.298	0.427	0.273 ± 0.401	0.024
Torque (degrees)	4.517 ± 3.153	<.001	6.114 ± 2.841	<.001	4.113 ± 3.486	<.001	5.337 ± 2.775	<.001	6.334 ± 3.260	<.001	6.174 ± 4.382	<.001
Rotation (degrees)	4.151 ± 3.379	<.001	7.031 ± 3.025	<.001	4.116 ± 2.454	<.001	4.306 ± 2.806	<.001	6.771 ± 3.315	<.001	5.180 ± 3.082	<.001
Tip (degrees)	3.880 ± 2.357	<.001	3.771 ± 2.804	<.001	4.881 ± 3.348	<.001	5.145 ± 3.109	<.001	5.805 ± 2.985	<.001	6.331 ± 4.345	<.001

Appendix A.3 Table of mean and standard deviation of placement error of lower right quadrant following a one-sample t-test with test value equals 0

	LR1					
	Bar n=13	***p* value**	**Silicone** n=12	***p* value**	**SMP** n=13	***p* value**
Mesiodistal (mm)	-0.044 ± 0.066	0.034	-0.022 ± 0.139	0.600	-0.006 ± 0.063	0.726
Occluso-gingival (mm)	-0.140 ± 0.324	0.144	-0.357 ± 0.161	<.001	-0.050 ± 0.379	0.641
Bucco-lingual (mm)	0.095 ± 0.124	0.017	0.132 ± 0.142	0.008	0.122 ± 0.116	0.003
Torque (degrees)	6.436 ± 2.464	<.001	4.109 ± 2.819	<.001	3.347 ± 3.331	0.003
Rotation (degrees)	4.078 ± 2.820	<.001	3.559 ± 2.048	<.001	2.069 ± 0.990	<.001
Tip (degrees)	5.097 ± 2.294	<.001	3.320 ± 3.557	0.008	3.843 ± 2.971	<.001

	LR2						LR3					
	Bar n=14	***p* value**	**Silicone** n=13	***p* value**	**SMP** n=15	***p* value**	**Bar** n=13	***p* value**	**Silicone** n=14	***p* value**	**SMP** n=15	***p* value**
Mesiodistal (mm)	-0.001 ± 0.087	0.974	-0.054 ± 0.101	0.077	0.011 ± 0.085	0.613	0.039 ± 0.102	0.196	-0.009 ± 0.063	0.606	0.065 ± 0.084	0.009
Occluso-gingival (mm)	-0.081 ± 0.365	0.418	-0.350 ± 0.129	<.001	-0.138 ± 0.344	0.143	0.019 ± 0.341	0.843	-0.029 ± 0.195	0.588	0.034 ± 0.285	0.647
Bucco-lingual (mm)	0.066 ± 0.103	0.032	0.162 ± 0.131	<.001	0.086 ± 0.105	0.007	-0.045 ± 0.069	0.037	-0.142 ± 0.153	0.004	-0.051 ± 0.119	0.116
Torque (degrees)	6.656 ± 3.419	<.001	3.624 ± 1.822	<.001	4.205 ± 3.399	<.001	4.863 ± 2.087	<.001	4.434 ± 1.052	<.001	5.248 ± 1.985	<.001
Rotation (degrees)	4.197 ± 2.189	<.001	4.482 ± 1.785	<.001	2.170 ± 1.155	<.001	3.619 ± 1.838	<.001	4.473 ± 1.922	<.001	3.821 ± 1.114	<.001
Tip (degrees)	5.683 ± 3.256	<.001	3.425 ± 1.446	<.001	4.621 ± 3.286	<.001	4.097 ± 2.404	<.001	4.611 ± 1.912	<.001	3.599 ± 2.114	<.001

	LR4						LR5					
	Bar n=15	***p* value**	**Silicone** n=15	***p* value**	**SMP** n=15	***p* value**	**Bar** n=15	***p* value**	**Silicone** n=13	***p* value**	**SMP** n=14	***p* value**
Mesiodistal (mm)	0.087 ± 0.119	0.013	0.164 ± 0.127	<.001	0.029 ± 0.111	0.332	0.144 ± 0.137	0.001	0.181 ± 0.238	0.018	0.063 ± 0.113	0.059
Occluso-gingival (mm)	-0.223 ± 0.277	0.007	-0.223 ± 0.209	0.001	-0.005 ± 0.328	0.957	-0.365 ± 0.242	<.001	-0.185 ± 0.173	0.002	0.143 ± 0.387	0.190
Bucco-lingual (mm)	-0.101 ± 0.145	0.018	-0.180 ± 0.183	0.002	-0.124 ± 0.184	0.020	-0.192 ± 0.128	<.001	-0.123 ± 0.180	0.029	-0.203 ± 0.181	0.001
Torque (degrees)	5.138 ± 2.098	<.001	5.550 ± 2.419	<.001	4.973 ± 1.254	<.001	4.750 ± 2.560	<.001	6.291 ± 2.935	<.001	5.128 ± 2.772	<.001
Rotation (degrees)	4.670 ± 1.920	<.001	4.842 ± 2.006	<.001	6.031 ± 1.333	<.001	5.272 ± 2.423	<.001	5.077 ± 1.811	<.001	6.901 ± 3.265	<.001
Tip (degrees)	4.689 ± 2.737	<.001	3.361 ± 2.268	<.001	4.069 ± 1.287	<.001	5.355 ± 2.514	<.001	5.842 ± 3.267	<.001	6.957 ± 2.687	<.001

	LR6						LR7					
	Bar n=14	***p* value**	**Silicone** n=15	***p* value**	**SMP** n=11	***p* value**	**Bar** n=13	***p* value**	**Silicone** n=11	***p* value**	**SMP** n=11	***p* value**
Mesiodistal (mm)	0.131 ± 0.258	0.080	0.072 ± 0.185	0.154	0.040 ± 0.152	0.398	0.274 ± 0.273	0.004	0.172 ± 0.290	0.078	0.002 ± 0.131	0.963
Occluso-gingival (mm)	0.486 ± 0.741	0.029	-0.105 ± 0.275	0.163	0.507 ± 0.536	0.010	0.270 ± 0.232	0.001	0.058 ± 0.301	0.540	0.217 ± 0.682	0.317
Bucco-lingual (mm)	0.264 ± 0.410	0.031	-0.126 ± 0.215	0.039	-0.093 ± 0.233	0.215	0.296 ± 0.383	0.016	-0.090 ± 0.244	0.250	-0.147 ± 0.390	0.239
Torque (degrees)	6.100 ± 2.120	<.001	7.813 ± 3.116	<.001	3.619 ± 1.779	<.001	6.093 ± 3.218	<.001	6.449 ± 2.083	<.001	5.471 ± 3.363	<.001
Rotation (degrees)	5.921 ± 2.645	<.001	8.197 ± 3.813	<.001	4.782 ± 2.350	<.001	7.392 ± 3.550	<.001	5.568 ± 3.662	<.001	6.013 ± 2.722	<.001
Tip (degrees)	5.855 ± 3.180	<.001	5.021 ± 3.835	<.001	5.146 ± 2.298	<.001	7.381 ± 3.899	<.001	6.584 ± 3.634	<.001	6.448 ± 3.801	<.001

Appendix A.4 Table of mean and standard deviation of placement error of lower left quadrant following a one-sample t-test with test value equals 0

	LL1					
	Bar	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**
	n= 12		n=13		n=14	
Mesiodistal (mm)	-0.022 ± 0.074	0.320	-0.002 ± 0.086	0.935	0.034 ± 0.058	0.048
Occluso-gingival (mm)	-0.047 ± 0.397	0.690	-0.357 ± 0.159	<.001	0.116 ± 0.477	0.380
Bucco-lingual (mm)	0.071 ± 0.114	0.054	0.092 ± 0.108	0.010	0.170 ± 0.163	0.002
Torque (degrees)	7.384 ± 2.902	<.001	3.266 ± 1.443	<.001	3.999 ± 3.311	<.001
Rotation (degrees)	4.541 ± 2.892	<.001	4.833 ± 2.354	<.001	3.300 ± 1.949	<.001
Tip (degrees)	5.626 ± 2.997	<.001	4.335 ± 2.637	<.001	3.774 ± 2.731	<.001

	LL2						LL3					
	Bar	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**	**Bar**	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**
	n=14		n=14		n= 15		n=14		n=15		n=15	
Mesiodistal (mm)	-0.046 ± 0.057	0.010	0.004 ± 0.070	0.852	0.043 ± 0.099	0.118	0.061 ± 0.096	0.033	0.042 ± 0.083	0.073	0.100 ± 0.120	0.006
Occluso-gingival (mm)	0.000 ± 0.353	0.998	-0.294 ± 0.129	<.001	0.051 ± 0.466	0.678	-0.167 ± 0.324	0.077	-0.073 ± 0.126	0.041	0.183 ± 0.333	0.052
Bucco-lingual (mm)	0.049 ± 0.046	0.002	0.136 ± 0.097	<.001	0.217 ± 0.175	<.001	-0.019 ± 0.096	0.468	0.040 ± 0.085	0.091	0.050 ± 0.122	0.135
Torque (degrees)	6.407 ± 3.256	<.001	4.092 ± 2.302	<.001	4.064 ± 2.938	<.001	4.479 ± 3.238	<.001	3.316 ± 2.068	<.001	3.138 ± 2.180	<.001
Rotation (degrees)	3.818 ± 2.291	<.001	4.598 ± 2.195	<.001	3.568 ± 3.205	<.001	3.648 ± 1.355	<.001	4.707 ± 2.731	<.001	2.945 ± 1.795	<.001
Tip (degrees)	5.966 ± 3.686	<.001	3.896 ± 2.193	<.001	3.389 ± 1.930	<.001	4.908 ± 2.694	<.001	4.659 ± 2.443	<.001	3.553 ± 2.780	<.001

	LL4						LL5					
	Bar	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**	**Bar**	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**
	n=15		n=15		n=15		n=15		n=14		n=13	
Mesiodistal (mm)	0.187 ± 0.145	<.001	0.256 ± 0.113	<.001	0.096 ± 0.148	0.024	0.154 ± 0.132	<.001	0.112 ± 0.126	0.005	0.018 ± 0.178	0.716
Occluso-gingival (mm)	-0.382 ± 0.344	<.001	-0.374 ± 0.209	<.001	0.178 ± 0.313	0.045	-0.426 ± 0.222	<.001	-0.222 ± 0.203	0.001	0.319 ± 0.233	<.001
Bucco-lingual (mm)	0.140 ± 0.155	0.004	0.196 ± 0.188	0.001	0.174 ± 0.160	<.001	0.139 ± 0.184	0.011	0.101 ± 0.170	0.045	0.132 ± 0.160	0.012
Torque (degrees)	4.634 ± 2.447	<.001	4.621 ± 2.966	<.001	3.533 ± 2.041	<.001	5.553 ± 3.032	<.001	6.788 ± 2.678	<.001	3.479 ± 1.297	<.001
Rotation (degrees)	3.806 ± 2.184	<.001	3.537 ± 1.878	<.001	5.915 ± 4.491	<.001	4.069 ± 2.605	<.001	5.049 ± 2.222	<.001	5.883 ± 1.626	<.001
Tip (degrees)	5.457 ± 2.715	<.001	5.082 ± 2.639	<.001	6.440 ± 4.874	<.001	6.009 ± 3.501	<.001	6.341 ± 3.141	<.001	5.056 ± 2.260	<.001

	LL6						LL7					
	Bar	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**	**Bar**	***p* value**	**Silicone**	***p* value**	**SMP**	***p* value**
	n=14		n=14		n=10		n=15		n=11		n=11	
Mesiodistal (mm)	0.155 ± 0.294	0.070	0.010 ± 0.222	0.869	0.012 ± 0.164	0.828	0.254 ± 0.226	<.001	0.109 ± 0.246	0.173	0.043 ± 0.180	0.446
Occluso-gingival (mm)	0.260 ± 0.261	0.003	0.207 ± 0.252	0.009	0.425 ± 0.580	0.046	0.155 ± 0.233	0.022	0.239 ± 0.207	0.003	0.325 ± 0.444	0.036
Bucco-lingual (mm)	-0.090 ± 0.118	0.013	-0.091 ± 0.272	0.234	-0.030 ± 0.259	0.721	-0.137 ± 0.173	0.008	0.071 ± 0.202	0.27	0.005 ± 0.292	0.952
Torque (degrees)	4.906 ± 2.762	<.001	6.510 ± 3.653	<.001	4.468 ± 3.539	0.003	6.078 ± 3.928	<.001	3.909 ± 2.976	0.001	4.200 ± 3.449	0.002
Rotation (degrees)	5.054 ± 3.574	<.001	6.352 ± 3.496	<.001	3.722 ± 1.728	<.001	4.969 ± 2.927	<.001	4.552 ± 3.112	<.001	6.464 ± 5.793	0.004
Tip (degrees)	5.341 ± 4.151	<.001	3.680 ± 1.941	<.001	5.510 ± 3.258	<.001	5.730 ± 3.444	<.001	3.844 ± 2.913	0.001	7.379 ± 6.431	0.003

Appendix A.5 Mean and standard deviation of upper right quadrant to assess mean differences between the three techniques. Student paired t-test was used to investigate the difference between the technique pairs. Statistically significant level was set at 0.05

	UR1						
	Bar 1T n=11	Silicone 2T n=11	SMP 3T n=11	ANOVA	1T-2T	1T-3T	2T-3T
Mesiodistal (mm)	0.074 ± 0.173	0.055 ± 0.128	-0.029 ± 0.123	NS			
Occluso-gingival (mm)	-0.311 ± 0.418	-0.028 ± 0.230	-0.439 ± 0.293	0.011	0.048		<0.001
Bucco-lingual (mm)	0.181 ± 0.148	0.181 ± 0.151	0.383 ± 0.163	0.003		0.01	0.008
Torque (degrees)	4.482 ± 3.007	4.084 ± 2.297	3.210 ± 1.894	NS			
Rotation (degrees)	4.414 ± 2.967	5.660 ± 2.946	2.409 ± 1.194	0.032		0.009	0.004
Tip (degrees)	5.988 ± 2.669	4.631 ± 2.927	3.106 ± 1.746	NS			

	UR2							UR3						
	Bar 1T n=9	Silicone 2T n=9	SMP 3T n=9	ANOVA	1T-2T	1T-3T	2T-3T	Bar 1T n=10	Silicone 2T n=10	SMP 3T n=10	ANOVA	1T-2T	1T-3T	2T-3T
Mesiodistal (mm)	0.146 ± 0.194	0.017 ± 0.178	0.042 ± 0.123	NS				0.147 ± 0.118	0.073 ± 0.250	0.186 ± 0.134	NS			
Occluso-gingival (mm)	-0.115 ± 0.470	0.010 ± 0.246	-0.311 ± 0.248	NS				-0.035 ± 0.288	-0.102 ± 0.342	-0.159 ± 0.334	NS			
Bucco-lingual (mm)	0.069 ± 0.106	0.041 ± 0.143	0.243 ± 0.150	0.025		0.031	0.0067	0.054 ± 0.063	0.024 ± 0.232	-0.083 ± 0.173	NS			
Torque (degrees)	7.475 ± 4.576	5.589 ± 1.463	5.435 ± 2.197	NS				6.222 ± 2.945	5.377 ± 1.742	4.337 ± 3.620	NS			
Rotation (degrees)	2.468 ± 1.058	6.771 ± 2.616	3.490 ± 1.934	0.001			0.021	4.405 ± 2.184	6.413 ± 1.900	3.127 ± 1.574	0.008			0.002
Tip (degrees)	7.075 ± 4.926	5.445 ± 2.418	5.095 ± 3.067	NS				6.168 ± 2.970	6.493 ± 1.803	5.288 ± 3.497	NS			

	UR4							UR5						
	Bar 1T n=13	Silicone 2T n=13	SMP 3T n=13	ANOVA	1T-2T	1T-3T	2T-3T	Bar 1T n=12	Silicone 2T n=12	SMP 3T n=12	ANOVA	1T-2T	1T-3T	2T-3T
Mesiodistal (mm)	0.056 ± 0.049	0.089 ± 0.108	-0.018 ± 0.105	0.002	NS	0.014	0.001	0.032 ± 0.130	0.069 ± 0.089	-0.099 ± 0.089	0.004		0.012	<0.001
Occluso-gingival (mm)	0.164 ± 0.245	-0.061 ± 0.241	0.098 ± 0.302	NS				0.252 ± 0.248	-0.002 ± 0.245	0.188 ± 0.324	0.045	0.025		0.006
Bucco-lingual (mm)	0.118 ± 0.103	0.050 ± 0.137	-0.112 ± 0.148	0.001		<0.001	0.024	0.163 ± 0.121	0.002 ± 0.163	-0.121 ± 0.262	0.003	0.001	0.005	
Torque (degrees)	3.725 ± 1.498	2.957 ± 1.062	2.904 ± 1.523	NS				6.558 ± 2.814	4.169 ± 2.026	3.048 ± 2.267	0.005	0.026	<0.001	
Rotation (degrees)	3.578 ± 1.417	3.733 ± 2.007	2.569 ± 1.283	NS				5.386 ± 2.372	3.839 ± 2.184	3.648 ± 2.213	NS			
Tip (degrees)	4.111 ± 1.634	3.717 ± 1.919	3.070 ± 1.592	NS				5.604 ± 2.573	3.526 ± 1.618	3.839 ± 2.537	0.036	0.021	0.028	

	UR6							UR7						
	Bar 1T n=13	Silicone 2T n=13	SMP 3T n=13	ANOVA	1T-2T	1T-3T	2T-3T	Bar 1T n=11	Silicone 2T n=11	SMP 3T n=11	ANOVA	1T-2T	1T-3T	2T-3T
Mesiodistal (mm)	0.426 ± 0.446	0.157 ± 0.225	-0.146 ± 0.234	0.001		0.001	0.006	0.274 ± 0.424	0.174 ± 0.394	-0.155 ± 0.104	0.046		0.005	0.012
Occluso-gingival (mm)	-0.178 ± 0.418	0.217 ± 0.143	-0.200 ± 0.297	0.003	0.017		0.001	-0.384 ± 0.317	0.107 ± 0.248	-0.391 ± 0.432	0.008	0.007		0.009
Bucco-lingual (mm)	-0.095 ± 0.118	-0.074 ± 0.205	-0.240 ± 0.203	0.03		0.027		0.024 ± 0.244	0.032 ± 0.412	-0.223 ± 0.327	NS			
Torque (degrees)	6.676 ± 6.570	5.700 ± 3.270	4.921 ± 2.731	NS				5.398 ± 2.777	4.302 ± 2.854	5.369 ± 3.404	NS			
Rotation (degrees)	5.848 ± 5.692	6.954 ± 2.657	4.537 ± 2.411	NS				6.384 ± 3.967	4.794 ± 3.442	5.425 ± 2.118	NS			
Tip (degrees)	6.747 ± 4.432	5.624 ± 2.356	2.596 ± 2.559	0.013		0.029	0..014	6.691 ± 3.857	4.341 ± 3.200	6.103 ± 3.312	NS			

Appendix A.6 Mean and standard deviation of upper left quadrant to assess mean differences between the three techniques. Student paired t-test was used to investigate the difference between the technique pairs. Statistically significant level was set at 0.05

	UL1						
	Bar 1T n=11	**Silicone 2T** n=11	**SMP 3T** n=11	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
Mesiodistal (mm)	-0.023 ± 0.157	-0.005 ± 0.068	0.097 ± 0.154	NS			
Occluso-gingival (mm)	-0.007 ± 0.407	0.054 ± 0.165	-0.438 ± 0.429	0.012			<0.001
Bucco-lingual (mm)	0.108 ± 0.172	0.143 ± 0.130	0.310 ± 0.186	0.017		0.048	0.002
Torque (degrees)	6.343 ± 2.904	4.369 ± 1.580	3.758 ± 2.222	0.032		0.015	
Rotation (degrees)	3.410 ± 1.676	5.043 ± 1.958	2.376 ± 2.597	0.031			0.004
Tip (degrees)	5.318 ± 3.384	3.594 ± 2.379	2.807 ± 1.480	NS			

	UL2							UL3						
	Bar 1T n=14	**Silicone 2T** n=14	**SMP 3T** n=14	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**	**Bar 1T** n=12	**Silicone 2T** n=12	**SMP 3T** n=12	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
Mesiodistal (mm)	-0.102 ± 0.118	0.016 ± 0.082	0.030 ± 0.134	0.007	0.012	0.009		0.191 ± 0.183	0.091 ± 0.161	0.194 ± 0.176	NS			
Occluso-gingival (mm)	0.226 ± 0.423	0.048 ± 0.101	-0.026 ± 0.334	NS				0.245 ± 0.352	0.177 ± 0.166	0.039 ± 0.289	NS			
Bucco-lingual (mm)	0.041 ± 0.143	0.087 ± 0.129	0.227 ± 0.151	0.008		0.007		-0.096 ± 0.108	-0.075 ± 0.128	0.036 ± 0.214	NS			
Torque (degrees)	7.435 ± 2.936	3.994 ± 2.087	5.833 ± 3.952	0.034	0.004			6.915 ± 4.317	8.030 ± 4.255	6.353 ± 3.956	NS			
Rotation (degrees)	3.362 ± 2.280	4.018 ± 2.484	3.282 ± 2.446	NS				5.826 ± 4.551	6.729 ± 3.299	5.247 ± 2.068	NS			
Tip (degrees)	6.990 ± 2.814	3.663 ± 2.427	5.712 ± 3.355	0.016	0.001			7.806 ± 4.332	7.325 ± 2.844	6.609 ± 3.127	NS			

	UL4							UL5						
	Bar 1T n=15	**Silicone 2T** n=15	**SMP 3T** n=15	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**	**Bar 1T** n=15	**Silicone 2T** n=15	**SMP 3T** n=15	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
Mesiodistal (mm)	0.140 ± 0.150	0.149 ± 0.117	-0.005 ± 0.091	<0.001		0.001	0.002	0.056 ± 0.090	0.089 ± 0.194	-0.076 ± 0.089	0.003		<0.001	0.008
Occluso-gingival (mm)	0.084 ± 0.329	-0.070 ± 0.267	0.093 ± 0.285	NS				0.200 ± 0.243	-0.089 ± 0.363	0.017 ± 0.432	0.043	0.016		
Bucco-lingual (mm)	0.003 ± 0.095	-0.001 ± 0.132	0.274 ± 0.191	<0.001		<0.001	<0.001	0.036 ± 0.093	-0.055 ± 0.211	0.270 ± 0.232	<0.001		0.001	<0.001
Torque (degrees)	5.088 ± 2.703	6.907 ± 3.777	2.294 ± 1.642	<0.001		<0.001	0.001	4.546 ± 2.679	5.857 ± 3.361	3.515 ± 1.420	NS			
Rotation (degrees)	3.998 ± 2.626	5.398 ± 3.905	3.150 ± 1.675	NS				4.030 ± 2.166	5.514 ± 3.508	2.671 ± 1.231	0.019		0.045	0.011
Tip (degrees)	4.489 ± 2.789	5.262 ± 3.192	2.708 ± 1.420	NS				4.305 ± 2.815	5.075 ± 3.118	3.638 ± 1.313	NS			

	UL6							UL7						
	Bar 1T n=12	**Silicone 2T** n=12	**SMP 3T** n=12	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**	**Bar 1T** n=12	**Silicone 2T** n=12	**SMP 3T** n=12	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
Mesiodistal (mm)	0.286 ± 0.269	0.111 ± 0.312	-0.004 ± 0.168	0.03		0.011		0.321 ± 0.226	0.025 ± 0.216	-0.170 ± 0.155	<0.001	0.004	<0.001	0.008
Occluso-gingival (mm)	-0.183 ± 0.230	0.132 ± 0.194	-0.219 ± 0.354	0.006	0.003		0.007	-0.278 ± 0.194	0.042 ± 0.293	-0.549 ± 0.354	<0.001	0.01	0.044	0.003
Bucco-lingual (mm)	-0.016 ± 0.190	0.083 ± 0.284	0.220 ± 0.291	NS				-0.018 ± 0.153	0.107 ± 0.289	0.190 ± 0.369	NS			
Torque (degrees)	4.500 ± 3.292	-0.004 ± 0.168	3.680 ± 3.020	0.001			0.033	5.505 ± 2.893	5.673 ± 3.014	6.069 ± 4.748	NS			
Rotation (degrees)	3.993 ± 3.479	7.216 ± 3.157	3.887 ± 1.770	0.019	0.049		0.005	4.666 ± 2.880	6.355 ± 3.318	5.163 ± 3.340	NS			
Tip (degrees)	3.596 ± 2.216	3.916 ± 2.866	4.713 ± 3.204	NS				5.442 ± 3.109	5.816 ± 2.247	6.435 ± 4.686	NS			

Appendix A.7 Mean and standard deviation of lower right quadrant to assess mean differences between the three techniques. Student paired t-test was used to investigate the difference between the technique pairs. Statistically significant level was set at 0.05

	LR1						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=12	n=12	n=12				
Mesiodistal (mm)	-0.047 ± 0.068	-0.022 ± 0.139	-0.005 ± 0.065	NS			
Occluso-gingival (mm)	-0.119 ± 0.329	-0.357 ± 0.161	-0.033 ± 0.391	0.02			0.008
Bucco-lingual (mm)	0.102 ± 0.126	0.132 ± 0.142	0.126 ± 0.120	NS			
Torque (degrees)	6.411 ± 2.572	4.109 ± 2.819	3.415 ± 3.470	0.033	0.051	0.008	
Rotation (degrees)	4.154 ± 2.932	3.559 ± 2.048	2.143 ± 0.996	NS			
Tip (degrees)	5.011 ± 2.374	3.320 ± 3.557	3.973 ± 3.064	NS			

	LR2							LR3						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**	**Bar 1T**	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=12	n=12	n=12					n=12	n=12	n=12				
Mesiodistal (mm)	0.011 ± 0.082	-0.050 ± 0.104	0.007 ± 0.091	NS				0.028 ± 0.099	-0.012 ± 0.068	0.064 ± 0.070	0.051			0.014
Occluso-gingival (mm)	-0.114 ± 0.386	-0.338 ± 0.127	-0.146 ± 0.349	NS				-0.048 ± 0.250	-0.005 ± 0.201	0.016 ± 0.238	NS			
Bucco-lingual (mm)	0.055 ± 0.105	0.150 ± 0.129	0.092 ± 0.109	NS				-0.040 ± 0.070	-0.140 ± 0.159	-0.081 ± 0.113	0.028	0.046		0.027
Torque (degrees)	6.626 ± 3.708	3.424 ± 1.748	4.694 ± 3.633	NS				4.685 ± 2.074	4.598 ± 1.050	5.618 ± 2.063	NS			
Rotation (degrees)	4.089 ± 2.276	4.291 ± 1.720	2.047 ± 1.039	0.03		0.005	0.005	3.616 ± 1.920	4.725 ± 1.969	3.928 ± 1.221	NS			
Tip (degrees)	5.812 ± 3.425	3.426 ± 1.511	5.104 ± 3.464	NS				3.833 ± 2.306	4.976 ± 1.795	4.000 ± 2.105	NS			

	LR4							LR5						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**	**Bar 1T**	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=15	n=15	n=15					n=12	n=12	n=12				
Mesiodistal (mm)	0.087 ± 0.119	0.164 ± 0.127	0.029 ± 0.111	0.009			0.008	0.124 ± 0.144	0.154 ± 0.227	0.084 ± 0.098	NS			
Occluso-gingival (mm)	-0.223 ± 0.277	-0.223 ± 0.209	-0.005 ± 0.328	NS				-0.373 ± 0.267	-0.174 ± 0.176	0.059 ± 0.293	<0.001	0.007	<0.001	0.039
Bucco-lingual (mm)	-0.101 ± 0.145	-0.180 ± 0.183	-0.124 ± 0.184	NS				-0.211 ± 0.130	-0.125 ± 0.188	-0.227 ± 0.184	NS			
Torque (degrees)	5.138 ± 2.098	5.550 ± 2.419	4.973 ± 1.254	NS				4.589 ± 2.706	6.093 ± 2.973	4.953 ± 2.817	NS			
Rotation (degrees)	4.670 ± 1.920	4.842 ± 2.006	6.031 ± 1.333	NS				5.371 ± 2.689	4.824 ± 1.635	6.516 ± 3.208	NS			
Tip (degrees)	4.689 ± 2.737	3.361 ± 2.268	4.069 ± 1.287	NS				5.619 ± 2.644	6.052 ± 3.320	6.299 ± 2.227	NS			

	LR6							LR7						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**	**Bar 1T**	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=10	n=10	n=10					n=7	n=7	n=7				
Mesiodistal (mm)	0.141 ± 0.305	0.092 ± 0.188	0.051 ± 0.156	NS				0.190 ± 0.315	0.171 ± 0.293	-0.020 ± 0.129	NS			
Occluso-gingival (mm)	0.454 ± 0.822	-0.068 ± 0.249	0.361 ± 0.237	NS				0.313 ± 0.302	0.033 ± 0.373	0.300 ± 0.850	NS			
Bucco-lingual (mm)	0.295 ± 0.460	-0.141 ± 0.213	-0.078 ± 0.240	0.011	0.006			0.402 ± 0.489	-0.157 ± 0.241	-0.256 ± 0.456	0.037	0.008		
Torque (degrees)	6.062 ± 2.123	7.478 ± 3.202	3.817 ± 1.743	0.011	0.026		0.011	6.350 ± 3.756	5.991 ± 2.396	5.915 ± 3.622	NS			
Rotation (degrees)	5.577 ± 2.544	8.054 ± 3.480	4.174 ± 1.272	0.009			0.005	7.786 ± 4.455	6.155 ± 4.107	5.975 ± 2.973	NS			
Tip (degrees)	5.361 ± 2.875	5.016 ± 4.581	4.583 ± 1.416	NS				9.111 ± 4.233	6.042 ± 3.986	6.560 ± 4.050	NS			

Appendix A.8 Mean and standard deviation of lower left quadrant to assess mean differences between the three techniques. Student paired t-test was used to investigate the difference between the technique pairs. Statistically significant level was set at 0.05

	LL1						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=11	n=11	n=11				
Mesiodistal (mm)	-0.024 ± 0.077	0.020 ± 0.060	0.028 ± 0.065	NS			
Occluso-gingival (mm)	-0.009 ± 0.393	-0.406 ± 0.118	0.192 ± 0.512	0.005	0.019		0.006
Bucco-lingual (mm)	0.077 ± 0.118	0.083 ± 0.111	0.135 ± 0.164	NS			
Torque (degrees)	7.531 ± 2.996	3.510 ± 1.438	4.174 ± 3.512	0.01	0.003	0.033	
Rotation (degrees)	4.521 ± 3.032	5.043 ± 2.492	3.368 ± 2.208	NS			
Tip (degrees)	5.718 ± 3.125	4.507 ± 2.812	3.528 ± 2.973	NS			

	LL2						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=13	n=13	n=13				
Mesiodistal (mm)	-0.039 ± 0.053	0.010 ± 0.069	0.057 ± 0.100	0.008		0.008	
Occluso-gingival (mm)	-0.028 ± 0.352	-0.291 ± 0.133	0.107 ± 0.477	0.028	0.043		0.022
Bucco-lingual (mm)	0.047 ± 0.047	0.133 ± 0.100	0.241 ± 0.176	0.004	0.024	0.003	
Torque (degrees)	6.609 ± 3.297	4.241 ± 2.324	4.415 ± 2.974	NS			
Rotation (degrees)	3.855 ± 2.380	4.871 ± 2.022	3.854 ± 3.349	NS			
Tip (degrees)	6.048 ± 3.823	4.051 ± 2.202	3.491 ± 2.060	NS			

	LL3						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=14	n=14	n=14				
Mesiodistal (mm)	0.061 ± 0.096	0.033 ± 0.080	0.096 ± 0.124	NS			
Occluso-gingival (mm)	-0.167 ± 0.324	-0.067 ± 0.128	0.146 ± 0.312	0.026	0.035		0.018
Bucco-lingual (mm)	-0.019 ± 0.096	0.043 ± 0.087	0.038 ± 0.118	NS			
Torque (degrees)	4.479 ± 3.238	3.381 ± 2.130	3.085 ± 2.252	NS			
Rotation (degrees)	3.648 ± 1.355	4.788 ± 2.815	3.046 ± 1.818	NS			
Tip (degrees)	4.908 ± 2.694	4.800 ± 2.471	3.545 ± 2.884	NS			

	LL4						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=15	n=15	n=15				
Mesiodistal (mm)	0.187 ± 0.145	0.256 ± 0.113	0.096 ± 0.148	<0.001	0.033	0.011	0.001
Occluso-gingival (mm)	-0.382 ± 0.344	-0.374 ± 0.209	0.178 ± 0.313	<0.001		0.001	<0.001
Bucco-lingual (mm)	0.140 ± 0.155	0.196 ± 0.188	0.174 ± 0.160	NS			
Torque (degrees)	4.634 ± 2.447	4.621 ± 2.966	3.533 ± 2.041	NS			
Rotation (degrees)	3.806 ± 2.184	3.537 ± 1.878	5.915 ± 4.491	0.021		0.042	0.032
Tip (degrees)	5.457 ± 2.715	5.082 ± 2.639	6.440 ± 4.874	NS			

	LL5						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=12	n=12	n=12				
Mesiodistal (mm)	0.166 ± 0.146	0.114 ± 0.121	0.033 ± 0.178	NS			
Occluso-gingival (mm)	-0.474 ± 0.188	-0.164 ± 0.150	0.316 ± 0.244	<0.001	0.035	<0.001	<0.001
Bucco-lingual (mm)	0.165 ± 0.193	0.102 ± 0.181	0.152 ± 0.150	NS			
Torque (degrees)	5.317 ± 3.324	6.183 ± 2.373	3.305 ± 1.185	0.041		0.039	0.007
Rotation (degrees)	4.108 ± 2.836	5.049 ± 2.330	5.843 ± 1.691	NS			
Tip (degrees)	6.047 ± 3.738	5.574 ± 2.668	5.129 ± 2.344	NS			

	LL6						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=9	n=9	n=9				
Mesiodistal (mm)	0.208 ± 0.285	-0.033 ± 0.232	0.033 ± 0.158	NS			
Occluso-gingival (mm)	0.239 ± 0.302	0.203 ± 0.207	0.396 ± 0.607	NS			
Bucco-lingual (mm)	-0.092 ± 0.140	-0.077 ± 0.239	-0.011 ± 0.267	NS			
Torque (degrees)	4.553 ± 1.866	6.049 ± 3.411	4.860 ± 3.516	NS			
Rotation (degrees)	5.483 ± 4.360	5.726 ± 3.083	3.325 ± 1.260	NS			
Tip (degrees)	4.881 ± 4.610	4.759 ± 1.336	5.312 ± 3.392	NS			

	LL7						
	Bar 1T	**Silicone 2T**	**SMP 3T**	**ANOVA**	**1T-2T**	**1T-3T**	**2T-3T**
	n=8	n=8	n=8				
Mesiodistal (mm)	0.364 ± 0.248	0.142 ± 0.283	0.077 ± 0.197	0.023	0.04	0.001	
Occluso-gingival (mm)	0.195 ± 0.275	0.317 ± 0.186	0.425 ± 0.451	NS			
Bucco-lingual (mm)	-0.094 ± 0.129	0.003 ± 0.195	-0.064 ± 0.194	NS			
Torque (degrees)	7.672 ± 4.057	3.493 ± 2.852	4.288 ± 3.114	0.044		0.019	
Rotation (degrees)	6.553 ± 3.006	4.487 ± 3.222	7.601 ± 6.498	NS			
Tip (degrees)	7.159 ± 3.291	3.785 ± 3.082	8.041 ± 7.300	NS			

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