doi: 10.30934/kusbed.1528896 e-ISSN: 2149-8571

Kocaeli Üniversitesi Sağlık Bilimleri Dergisi

Özgün Araştırma / Original Article

http://dergipark.org.tr/kusbed

DOES OPERATOR-DEPENDENT INDIRECT BONDING TECHNIQUES DIFFER FROM THE AUTO-DETERMINED FACIAL AXIS POINT?

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Geliş Tarihi / Received: 08.08.2024 **Kabul Tarihi / Accepted:** 24.12.2024 **Yayım Tarihi / Published:** 21.03.2025

Abstract

Objective: Brackets are orthodontic attachments bonded to a tooth for the purpose of securing an orthodontic archwire. The aim of this study was to evaluate whether human error affects bracket position errors by comparing digital and analogue indirect bonding (IDB) techniques with fully digitized IDB protocols.

Methods: Thirty-six intraoral models were divided into three groups. Ten brackets were placed in each cast (incisors, canines, and premolars). In the automatic control group, brackets were placed according to facial axis point automatically calculated by Ortho Analyzer software. In the manual digital group (MDG) brackets were placed by an operator, while in the manual analogue group (MAG) brackets were placed on plaster models. Models were digitally superimposed and compared with control models (3D slicer). The linear and angular measurements were analyzed with Mann-Whitney U test and Chi-square test.

Results: There were statistically significant differences in vertical, tipping, torque, and rotation for incisors and in vertical and torque for canines when comparing MDG with MAG placement. The error frequencies showed that 81.1% of brackets in the MDG were within acceptable limits, whereas only 62.5% were acceptable in the MAG group. The prevalence of accuracy in MDG was higher in all variables except tipping.

Conclusion: Digital aids improved bracket position accuracy. Horizontal axis was the safest variable. Incisor of MAG showed increased discrepancy in all angular values and vertical dimension. Special consideration should be given to canines regarding vertical axis and torque errors in MAG. Angular positioning of premolars was more critical than linear positioning.

Keywords: *Dental bonding, artificial intelligence, software.*

Introduction

According to Andrews, brackets should be placed at the midpoint of the *facial axis* (FA), a point on the long axis of any tooth that is centered mesiodistal on the facial surface of a clinical crown, namely *facial axis of clinical crown*.[1] Accurate bracket placement on the FA point significantly decreases the need for archwire bendings or bracket repositioning. However, even under optimal conditions, ideal bracket placement during initial bonding is frequently impossible due to configurations of the clinical crown, operator error or patient management.[2,3]
Silverman et al.[4] first described an indirect bonding (IDB) technique as an attempt to improve the accuracy of bracket positioning. Brackets were first placed on dental casts before being transferred to patient's mouth using a custom-made IDB tray. It is reported that IDB results in higher bracket placement accuracy than the frequently used direct bonding (DB) method.[5] To precisely determine FA point on the casts, an orthodontic gauge or a periodontal probe may be used. Currently, with the incorporation of computer-aided design/computer-aided manufacturing (CAD/CAM) technology, available software programs can calculate teeth dimensions and place the bracket manually or even automatically on the FA point.[6] Therefore, it is believed that the ability to virtually measure tooth surface with greater precision will reduce precision errors and refinements during treatment.
Previous researches have focused on evaluating IDB protocols, with particular emphasis on transfer accuracy and bracket failures.[7-9] Various commercial systems have been released over the last decades, and they can be used to precisely place brackets based on computer-aided measurements, while reducing lab time. Nonetheless, bracket placement accuracy of CAD/CAM technology has not yet been thoroughly evaluated.
To the best of our knowledge, no study has compared accuracy differences between operator dependent techniques, where the FA point is determined by the operator, and these fully digitized techniques, where the FA point is auto-determined according to the dental anatomy data analyzed by the software. We hypothesized that accuracy levels of human error differ between operator-dependent and fully digitized IDB protocols. A further aim was to evaluate the differences in linear and angular changes of bracket positions between two non-automatic bracket placement procedures, as well as the error frequency of each technique.

Methods

This randomized, *in vitro* study was approved by the Ethical Committee of Marmara University, Faculty of Dentistry (Protocol No: 2021/27). The sample size was determined to be 120 brackets in each group. A *post-hoc* power analysis was performed with G*Power (Version 3.1.9.6, Heinrich-Heine-Universität, Düsseldorf, Germany) software. Twelve models per group yielded 96.1% power and an alpha of 0.05 to obtain an effect size of 1.44.
An orthodontic specialist with four years of experience with both techniques performed bracket placement. The same blinded operator (FK) placed brackets onto 12 cast models (manual analogue group, MAG) and 24 digital models (12 automatic control group, ACG; and 12 manual digital group, MDG) in a laboratory setting. Ten brackets (incisors, canines, and premolars) were placed on each cast. Each working group contained 120 brackets, the positions of which were compared to the ACG controls in terms of six parameters: horizontal; vertical; buccopalatal; rotation; tipping; and torque. To avoid any bias, brackets were positioned with a 15-day interval between groups (from tooth 15 to tooth 25), in the following order: 1) MDG; 2) MAG; and 3) ACG.
Models had to meet following inclusion criteria: (1) presence of all permanent teeth (excluding molars); (2) crowding up to 3 mm; and (3) no genetic syndromes related with the oral cavity. The exclusion criteria were casts with: (1) caries; (2) fluorosis or hypoplasia of enamel; (3) restorations or fractures of surfaces to be bonded; (4) abnormalities in crown morphology; (5) major rotations impeding proper bracket positioning; and (6) incomplete or poor-quality records.
Models were collected from the orthodontic archive of Marmara University. For each cast, there had to be a panoramic radiograph matching the date of cast fabrication. For the randomization process, models matching inclusion criteria were recorded in numerical order. Each paper was enclosed separately in an opaque, sealed envelope. A blinded person was required to choose 12 from a pool of 54 models. The selected 12 anonymized study models were scanned with an intraoral scanner (iTero, Align Technologies, San Jose, California, USA). Then 12 digital casts were copied once to create ACG and MDG. Thus, three evaluation groups were formed.

Automatic Control Group (ACG)

The models were imported into Ortho Analyzer™ software (3Shape, Copenhagen, Denmark), according to number and sequence given to the operator. After importing models, the digital bracket setup option was selected. Brackets were placed digitally following the steps: (1) determination of mesiodistal points of premolars, canines, and incisors by operator; (2) teeth auto-segmentation; (3) adjustment of root inclinations according to panoramic radiographs provided by operator; and (4) automatic bracket placement set on the computer determined FA point produced by the software algorithm. The virtual bracket positioning in optimum arch was created using 0.021x0.025" stainless steel (SS) archwire (G&H, Franklin, USA) to visualize final alignment. The models with virtual brackets attached were saved and validated in Ortho Analyzer™ and then exported as stereolithographic (STL) files. A blinded orthodontist (FK) served as operator and followed the steps that were required to introduce dental anatomy data into the software. If any deviation of automatic bracket placement position was noticed, steps 1, 2, and 3 were revised to ensure that necessary inputs for algorithm were made accurately.

Manual Digital Group (MDG)

The same software, brand, and bracket prescription were used. However, FA points were determined subjectively, based on the operator's visual assessment during the segmentation process (Figure 1). Then, the brackets were placed by the software according to the FA points that were determined manually by the operator. During the software's leveling and alignment outcome simulation, the final virtual alignment of arches was created using 0.021x0.025" SS archwire (G&H, Franklin, USA). This feature of the software levels and aligns the arches so that FA points are aligned on the same plane according to the prescription they would receive if 0.021x0.025" SS archwire was inserted. If necessary, the operator was able to rearrange bracket positions before validating the model. Following validation, STL files were again created for three-dimensional (3D) comparison.

Manual Analogue Group (MAG)

In MAG, the conventional IDB technique was used, performed using the following steps: 1) marking of vertical axis, buccal cusp, and the highest point of gingival margin of each tooth with a pencil in reference to the panoramic x-ray; 2) determination of the heights of bracket slot centers, using a periodontal probe, and marking the FA point on the casts; 3) applying a 1 mm layer of composite (GO composite, Reliance Orthodontic Products, Illinois, USA) and equally distribution on the base of metal bracket with a micro-brush; 4) applying pressure to each bracket for five seconds; 5) removing resin excess; 6) applying pressure again to ensure homogenous thickness of composite is attained; and 7) light-curing for 20 seconds. After polymerization, models were scanned with an intraoral scanner (iTero, Align Technologies, San Jose, Calif.), to create 12 STL files for 3D analysis.

Data Assessment

STL files were superimposed using 3D Slicer software (version 4.10.1, www.slicer.org). Control and working models were compared using automatic surface registration of virtual models based on an iterative closest point algorithm (Figure 2). The models from the ACG were used as reference. Two superimpositions were created from each control, for two working groups.

The variations in the position of each bracket in six dimensions (3 linear and 3 angular) were calculated and recorded with positive and negative values, according to direction (Figure 3).

The linear measurements were as follows:

1) Horizontal (mm): Mesial (+) and distal (-) translation of bracket,

2) Vertical (mm): Gingival (+) and occlusal (-) translation of bracket,

3) Buccopalatal (mm): Palatal (+) and buccal (-) translation of bracket.

The angular measurements were:

1) Tip angular difference (°): Distal tip (+), and mesial tip of bracket (-),

2) Torque angular difference (°): Incisopalatal and gingivobuccal direction (+), incisobuccal and gingivopalatal direction (-) of bracket,

3) Rotation angular difference (°): Mesiopalatally (+), and mesiobuccally (-) rotated bracket.

To accurately measure the difference between two bracket positions, a coordinated system at the center of the slot was created for each bracket in control and working casts. Distance and inclination difference between two systems were measured for each comparison (Figure 2).

Prevalence of Errors

To evaluate the prevalence of errors in bracket positioning, frequencies of errors that exceeded the clinical limit were compared by accepting deviation limits of 0.5 mm for linear dimensions and 1° for angulation, as described previously.[10,11]

Statistical Analysis

Statistical analyses were performed using SPSS, version 25.0 (IBM Corp, Armonk, NY, USA). Statistical significance level was set at $p<0.05$. Mann-Whitney U test was used to compare position errors in six aspects between two working groups and the control group, as well as the positions of each tooth category separately (incisors, canines, premolars). During statistical analyses, median values were used. As error values were either negative or positive based on the direction of discrepancy, the summation of these values could negate each other. The sample did not conform to normal distribution. Thus, intergroup differences were assessed using Mann-Whitney U test. Chi-square test was used to determine the prevalence of clinically acceptable transfer errors. Frequencies of errors that exceeded the clinical limit were compared to assess the prevalence of errors in bracket placement.

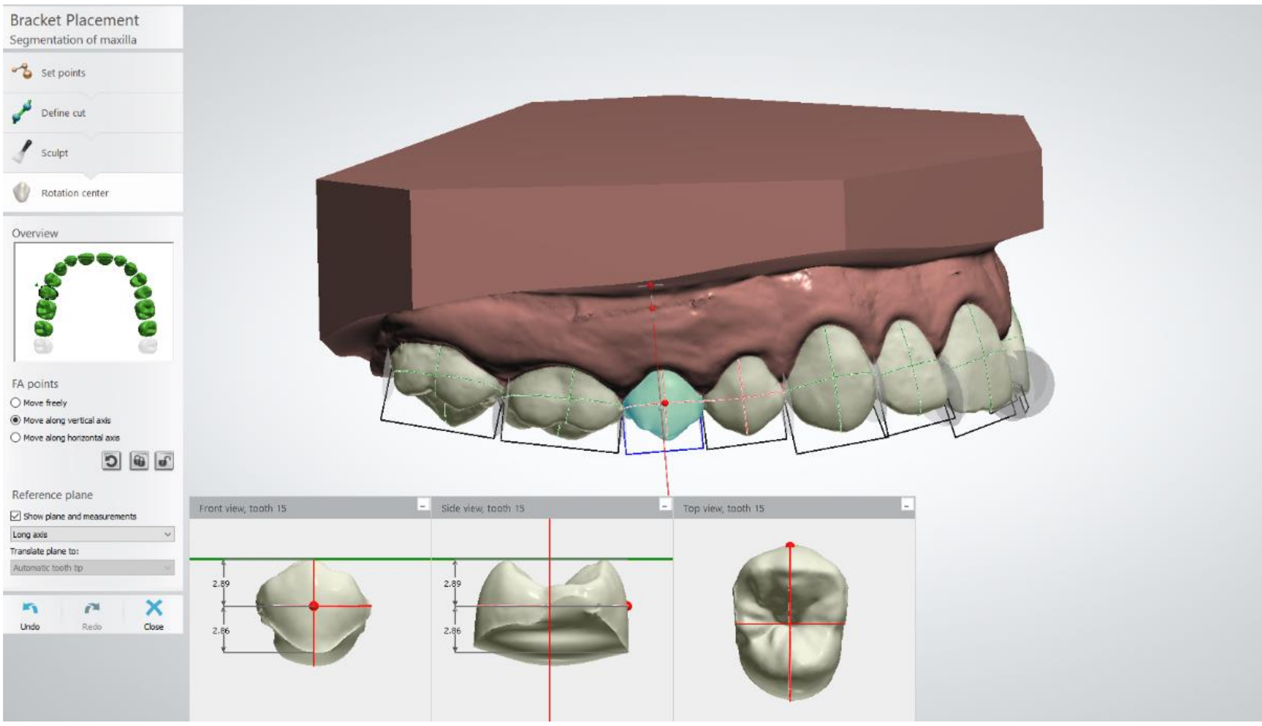

Figure 1: Adjustment and determination of facial axis point

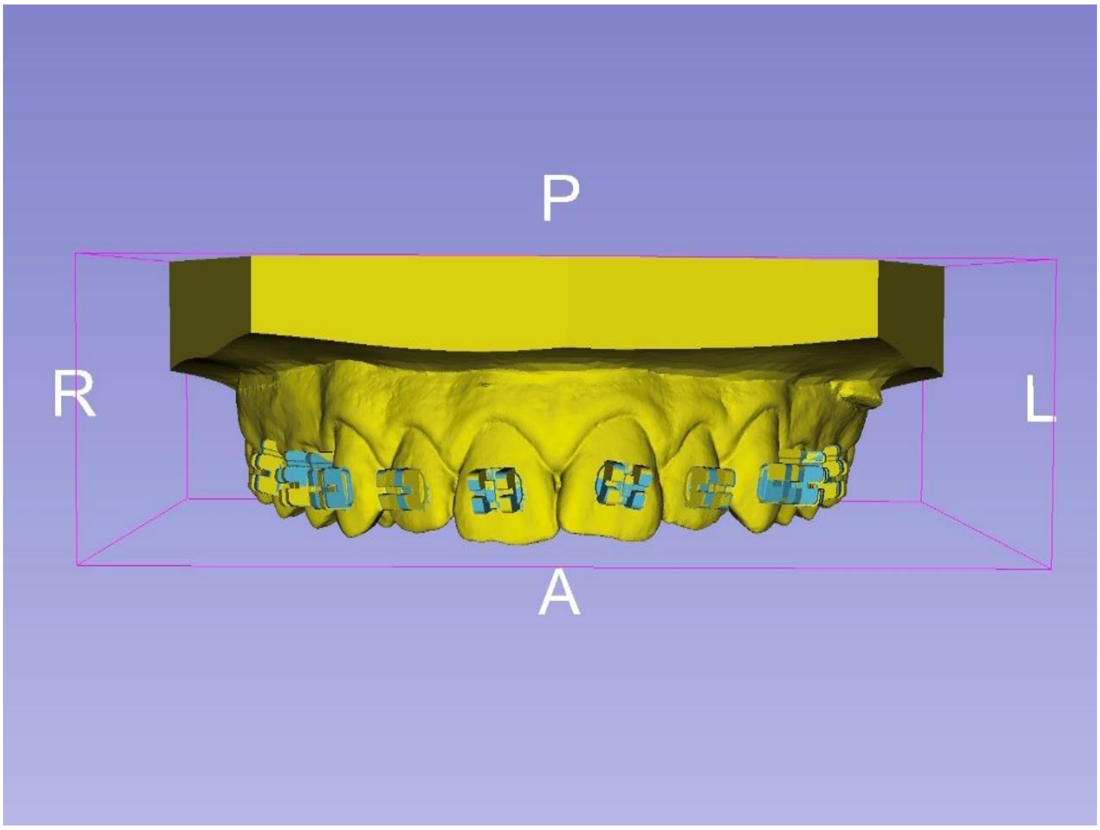

Figure 2: Automatic surface registration superimposition of control (yellow) and working group (blue) models accompanied by coordinated system at the center of slot was created for each bracket measurements

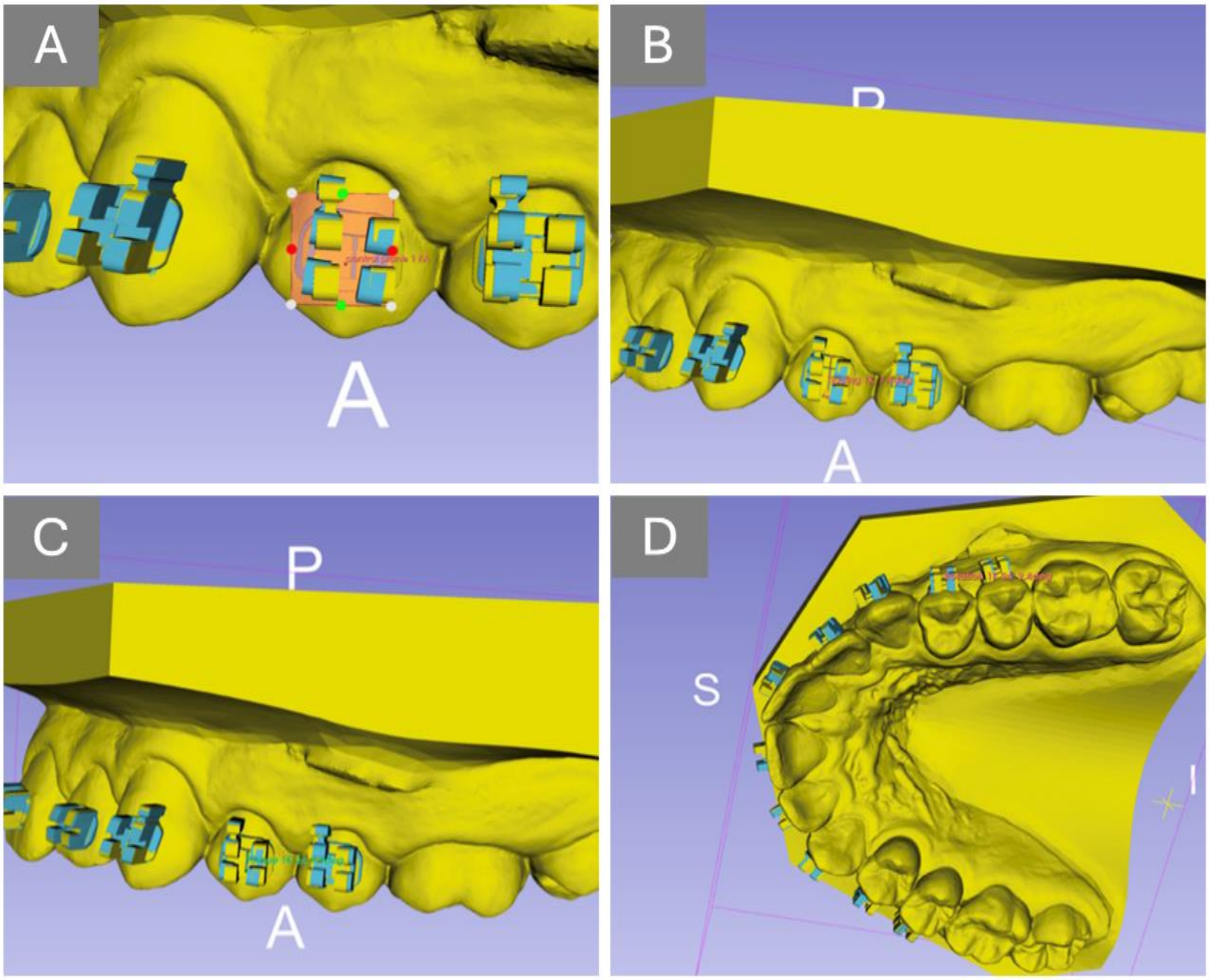

Figure 3: Determination of the deviations; A: Linear, B: Tip angular, C: Torque angular, D: Rotation angular

Results

Frequency of Error Analysis

The two groups, MDG and MAG, were compared according to accuracy with the ACG positions regarded as reference for the purposes of this study. Based on limit values, there were two levels of Errors: “Yes” or “No”, indicating the presence of acceptable placement accuracy or not. The results of error frequencies are presented in Table 1.

The accuracy frequency in MDG was higher in all variables except tipping, so that 81.1% of positions were within clinically acceptable limits. However, only 62.5% accuracy was achieved in the MAG group.

All dimensions differed significantly between MDG and MAG, except for tipping (p=0.011 for horizontal, p<0.001 for vertical, buccopalatal, torque and rotation). Tipping demonstrated comparable results in MDG and MAG, with 92 and 96 acceptable bracket positions, respectively. Besides, tipping dimension was the only parameter in which MAG exhibited percentile superiority.

Comparison of Error Positions between Groups by Tooth Type

The deviation of bracket positions, based on tooth type, are described in Table 2. The statistical analysis of incisors showed that error values were greater for all angular variables as well as vertical dimension in MAG.

Incisor brackets in MAG showed significantly higher discrepancies and were positioned more gingivally compared to MDG (p<0.001). Regarding angular parameters in MAG, incisors were distally root tipped (p=0.016), palatally crown torqued (p<0.001), and mesiopalatally rotated (p=0.040). In MDG, all values were within acceptable error range limits, except for tipping. While in MAG, vertical and angular parameters exceeded acceptable clinical norms. Canine brackets in MAG tend to be more gingival (p=0.038). Torque measurement of MAG indicated significantly higher palatal crown torque (p=0.021). In MDG, tipping and rotation were outside the clinical limit. Vertical and angular parameters exceeded the limit in MAG. Premolars showed no statistical significance between two groups. All linear parameters were within acceptable range, while angular parameters were outside acceptable limits.

Table 1: Frequency of bonding errors that exceeded the clinical limits

Variable	Group	Accuracy (n: 120) Yes n	Yes %	No n	No %	*p*
Horizontal	MDG	118	98.33	2	1.67	0.011*
	MAG	109	90.83	11	9.17	
Vertical	MDG	113	94.17	7	5.83	<0.001*
	MAG	78	65	42	35	
Buccolingual	MDG	117	97.5	3	2.5	<0.001*
	MAG	102	85	18	15	
Tipping	MDG	92	76.67	28	23.33	0.531
	MAG	96	80	24	20	
Torque	MDG	75	62.5	45	37.5	<0.001*
	MAG	23	19.17	97	80.83	
Rotation	MDG	69	57.5	51	42.5	<0.001*
	MAG	42	35	78	65	
Total	MDG	584	81.1	136	18.9	
	MAG	450	62.5	270	37.5	

Chi-square test, *p<0.05, MDG: Manual digital group, MAG: Manual analogue group

Table 2: Comparative analysis between digital and analogue bracket placement of teeth groups regard to error

Variable	Group	Incisors Mean	SD	Median	*p*	Canines Mean	SD	Median	*p*	Premolars Mean	SD	Median	*p*
Horizontal (mm)	MDG	-0.03	0.17	-0.01	0.263	-0.04	0.12	-0.03	0.211	0.07	0.25	-0.04	0.052
	MAG	0.00	0.35	0.06		-0.12	0.49	-0.02		0.10	0.28	0.04	
Vertical (mm)	MDG	0.06	0.18	0	<0.001*	-0.02	0.12	-0.03	0.038*	0.29	0.17	-0.03	0.930
	MAG	0.53	0.26	0.53		0.75	0.34	0.75		-0.11	0.71	0.37	
Buccolingual (mm)	MDG	-0.03	0.13	0.02	0.836	-0.07	0.19	0.01	0.749	-0.04	0.23	-0.03	0.384
	MAG	0.15	0.13	0.20		-0.15	0.22	-0.22		-0.38	0.23	-0.04	
Tipping (°)	MDG	1.85	1.41	1.40	0.016*	2.56	1.07	2.30	0.976	1.46	1.62	1.21	0.435
	MAG	2.60	1.91	2.39		2.84	1.14	2.35		1.87	1.61	1.37	
Torque (°)	MDG	0.26	0.47	0.05	<0.001*	-0.24	1.26	0.03	0.021*	1.57	1.55	1.36	0.052
	MAG	4.43	3.41	3.38		1.78	1.54	1.36		4.29	3.21	4.29	
Rotation (°)	MDG	0.71	0.64	0.53	0.040*	1.03	1.12	0.62	0.801	1.58	1.29	1.31	0.639
	MAG	1.97	1.06	1.53		2.90	2.51	2.27		3.04	3.38	0.81	

Mann Whitney U-test, *p<0.05, MDG: Manual digital group, MAG: Manual analogue group

Discussion

Inaccurate orthodontic bracket positioning can lead to various undesired results, including misalignment of dentition, potentially compromised oral health, and increased treatment duration.[12] As a result of undesired force direction, inefficient tooth movement or damage to adjacent roots may occur. If brackets with wrong positions are not corrected, they may cause poor treatment outcome, aesthetics, and long-term stability. Current research has not identified a consensus or proof of a gold standard on whether a specific bracket placement method has superiority over the DB technique.[12-14] Moreover, digital IDB studies have highlighted the difficulty of achieving accurate bracket placement clinically, as human error cannot be overlooked, and many factors might affect clinician's precision in bracket positioning.[15,16] Lack of placement accuracy also led researchers to the development of computer-assisted IDB protocols to reduce human error to a minimum by artificial intelligence (AI)-aided bracket placement.[15] To date, most studies have evaluated the quality of transfer media[17-20], while the aim of the current study was to compare placement accuracy of digital and analogue techniques with ACG, thereby understanding the effects of human error based on the positioning of the FA point in six dimensions, as well as the error frequency of each method, when accepting the ACG as the optimal placement.

The majority of previous studies employed photographic methods to measure deviations from optimum bracket position.[21,22] However, this method has disadvantages in precisely calculating errors due to magnification and distortion.[23] A more accurate method of measuring error values is 3D virtual model superimposition.[24-27] Variable techniques and software packages have been used to quantify tooth movement through 3D digital registration of virtual models.[28-30]

In auto-determined FA point registration, an operator defines mesiodistal distance and long axis of each tooth manually. Then, the software's algorithm places the bracket at the optimal FA point, with reference to mesiodistal and axial root inclination. An excellent agreement between measurements with conventional and 3D methods in three planes of space was found by previous studies.[31,32] Thus, 3D can be an alternative to conventional stone dental models. The accuracy of automatic bracket distribution was also demonstrated by Oliveira et al., who reported that AI-aid in IDB could contribute to greater assertiveness in bracket positioning.[33] In the present study, linear deviations and therefore the exact position differences of FA points between MDG and ACG were at a clinically negligible level. These findings were both in line with Oliveira's results, and also demonstrated the compatibility of the ACG and MDG techniques in terms of accuracy of bracket placement.

The criteria for defining clinically acceptable limits we used were based on previous studies.[10,11] When marginal ridge misalignment is less than 0.5 mm, the American Board of Orthodontics' Objective Grading improves. In addition, a previous study concerning facial asymmetry stated that a primary difference in asymmetry is the perception threshold of laypeople and prosthodontists.[11]

In linear parameters, there was no intergroup difference regarding horizontal dimension. It may be easier to determine the midpoint of the tooth according to anatomical references than those of adjustment of angulation and vertical placement. Oliveira et al. had the most similar method, since there was no study comparing digital and analogue IDB techniques. They found that horizontal precision of automatic indirect bracket placement was greater when compared DB using the same software. Nonetheless, their mean errors (0.097mm mesial for incisors, 0.167mm mesial for canines, 0.016mm distal for premolars) were comparatively worse than the current study's results. They also concluded that automatic virtual technique showed predominance in placement accuracy over DB, promising advantages of AI.[33] The vertical positioning difference between groups was significant in incisor and canines. For both tooth groups, mean error of MAG was above limit. It is expected that tooth groups with increased crown height have a propensity for vertical errors. Furthermore, the higher success rate in MDG can be attributed to the ability to digitally zoom in on the image. In Oliveira's study, virtual resources contributed to a higher precision, especially in vertical parameters.[33] In the current study, a similar difference was also observed regarding vertical accuracy. The percentage exhibited a dramatic increase (94.17%) when brackets were placed automatically by software. Moreover, absence of intergroup differences in buccopalatal dimension ensured that composite thickness was not a significant variable in the methodology of the present study.

In terms of angular parameters, MAG was greater than MDG in the tipping dimension of incisors. However, both groups exhibited higher mean error than the clinical limit, similar to the findings of Oliveira et al..[33] Incisors are a group of teeth with no anatomical reference, such as buccal ridge, which may be challenging when determining axial inclination. Mostly, abrasions due to anterior guidance may mislead the operator. Torque errors were greater in the MAG for both incisors and canines, and exceeded the clinically acceptable limit. Rotation error was greater for incisors in the MAG, with MAG exceeding acceptable limit, while MDG did not. These two variables may be related to maladaptation of bracket base due to anatomic variability of buccal surface, or operator error for those who did not adapt the bracket properly. Similar earlier studies evaluating angular differences in virtual bracket placement have not analyzed torque, tipping and rotation and thus positional differences in angular parameters cannot be compared.

Composite thickness can be acknowledged as a limitation, especially regarding buccopalatal, torque, and rotation. This is because the amount of adhesive gap between tooth and bracket base can be standardized with software. However, in the manual method, the technique requires special attention from the operator, since the thickness of adhesive is prone to variations. To reduce the error that might be caused by composite thickness, the same operator with analogue IDB experience performed all bracket placements, ensuring that sufficient force was applied for thorough base adaptation[34] and sufficient time was spent for the release of entire flash. The potential impact of operator experience on bracket placement accuracy can also not be underestimated, and may be studied in the future by comparing several operators. Moreover, to avoid inherent variability of the manual technique, the methodology was determined precisely and step-by-step. Moreover, the current study was designed as a bracket placement accuracy study, rather than a transfer accuracy study. This was because the more the IDB step is included in the study design, such as fabrication method or thickness of tray and intraoral transfer procedures, the harder it is to determine the source of error.

Although the methodology of the present study provided a novel approach to evaluating IDB errors *in vitro*, several future enhancements may improve the knowledge of this specific topic, such as difference in preparation time between the two techniques. Moreover, following steps of the procedures may be compared, such as *in vivo* accuracy and failure rates of techniques. Incorporation of 3D imaging tools would also enhance the accuracy evaluation of bracket positioning.

Conclusion

The following key findings emerged from the present study:

- Digital aids improved bracket position accuracy, with respect to the FA point;
- The error frequencies revealed that manual analogue bonding requires more attention than the manual/digital technique;
- In both groups, the parameter with the lowest discrepancy was the horizontal axis;
- Incisor brackets of MAG showed increased discrepancy in all angular values, as well as vertical dimension, supporting the advantages of digital aids in these dimensions;
- Special consideration should be given to canines regarding vertical axis and torque errors in MAG;
- Premolars showed better linear precision but angular positioning was more critical;
- The promising advantages of digital tools in IDB may lead to the development of new IDB protocols.

Conflict of interest
The authors declare that they have no competing interests.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical approval
Ethical approval was obtained from the Ethical Committee of Marmara University, Faculty of Dentistry (Approval number: 2021/27)

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