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Accuracy of computer-aided indirect bonding using hard resin trays

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ABSTRACT

Objective Many computer-aided solutions for indirect bonding have been proposed to increase the accuracy of bracket placement. The purpose of this study is to evaluate the accuracy of bracket placement using hard three-dimensional (3D) printed transfer trays.

Method: Virtual bracket placement was performed on digitally scanned upper arches; transfer trays were virtually designed and 3D-printed using hard resin material. The transfer trays were used to indirectly bond one hundred brackets on the patients' upper arches. The actual bracket positions were scanned after bonding, and virtual versus actual models were superimposed to measure linear and angular deviations from the planned positions.

Result: The mean linear transfer errors were 0.315 ±0.025 mm mesiodistally and 0.366 ±0.014 mm occlusogingivally, with brackets tending toward distal and incisal positions. Angular errors averaged 1.632° ±0.091° for tip and 1.245° ±0.069° for rotation, showing directional bias toward clockwise tipping and mesial-in rotation compared to the planned positions.

Conclusion: Indirect bonding with 3D-printed hard trays provides clinically acceptable accuracy in transferring bracket positions from the virtual setup to the patient's dentition in both linear and angular dimensions

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1. INTRODUCTION

The most popular method for fixed orthodontic treatment is the straight-wire technique, which Andrew developed.(1) It is essential to place the brackets precisely in this technique, and with the proper archwire, they deliver the desired mechanical effect(2).

Inaccurate bracket placement might necessitate the repositioning of brackets or the insertion of additional compensatory bends(3) that lead to an extended treatment time(4). Also, undesirable tooth movement is expected as a result of inaccurate bracket positioning(5).

There are two main techniques for positioning the orthodontic brackets. The first, more widely used method is direct bonding: the brackets are adjusted directly on the patients' teeth. There are several drawbacks associated with this technique, such as limited access to the surfaces of malaligned teeth, increased chair time, greater possibility of moisture contamination, and poor visualization of posteriors.(6)

The indirect bonding (IDB) technique was first published by Silverman et al.(7) In the classical indirect bonding technique, brackets are positioned on plaster models, and transfer templates are fabricated in the laboratory, which are frequently made of single- or double-layer silicones, vacuum-formed sheets of various thicknesses, or a combination of both.(8) Both the silicon-based and vacuum-formed techniques were accurate and reliable within the clinically acceptable ranges.(9-11)

IDB has increased in popularity due to unimpaired visibility during bracket positioning, improved patient comfort, and reduced chairside time.[8, 12, 13] Several studies have reported that the IDB trays lead to higher bracket placement accuracy than the usually used direct bonding techniques.[14]

Advancements in digital orthodontics have replaced traditional manual workflows with more efficient techniques. Intraoral scanners now provide accurate virtual models with reduced patient discomfort[15, 16], while digital software enables semiautomated bracket positioning.[17] Transfer trays can be either manually fabricated from printed models[18] or directly 3D printed using biocompatible resins [19-21] with high transfer accuracy.[22, 23]

2. MATERIAL AND METHOD

Ten patients seeking orthodontic treatment at the outpatient orthodontic clinic, Faculty of Dental Medicine, Al-Azher University, Assiut branch, were enrolled in this study. The inclusion criteria were the presence of a full complement of maxillary dentition from first molar to first molar, good oral hygiene, healthy periodontium, and spaced upper arch or crowding no more than 4 mm.

The exclusion criteria were patients with primary teeth, missed permanent teeth (except 2nd and 3rd molars), malformed teeth, impacted teeth, enamel fluorosis, partially erupted teeth, restored teeth, and teeth with major rotation impeding proper bracket positioning.

A written consent was signed by each patient or his/her guardian to adhere to the protocol of this study.

Three-dimensional data acquisition, virtual bracket placement, and tray designing.

Digital impressions of the upper arches were acquired using an intraoral scanner and processed for transfer tray design. Teeth were individually segmented on the initial model (M0), and fixed metallic brackets (Discovery Smart®, Dentaurum, Germany; 0.022 × 0.028-inch slot with hooks on canines and premolars) were virtually positioned from incisors to second premolars with automated placement and manual adjustments. The finalized bracket model (M1) was saved as a reference. Transfer trays with supports were then digitally designed, 3D printed in biocompatible hard resin, post-processed, and sectioned at the midline for easier clinical application

Clinical bracket transfer

Brackets were positioned into their respective molds in the transfer tray, and a thin layer of Grengloo® adhesive was applied to each bracket base. The upper arch was etched with 37% phosphoric acid, rinsed, and dried, followed by application of Ortho Solo® primer. The loaded transfer tray was seated quadrant by quadrant, and brackets were light-cured for 20 seconds each. The tray was then carefully removed using a scaler to disengage occlusally. A second intraoral scan was performed immediately after bonding to obtain the post-bonding model (M2), capturing the dental arches with bonded brackets.

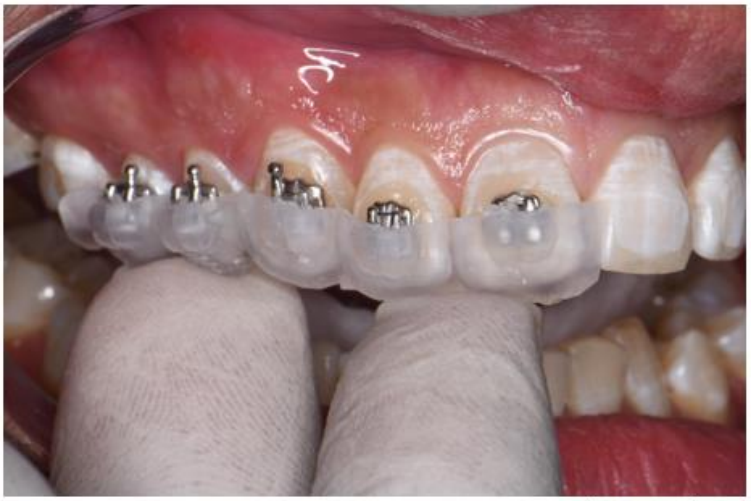

Figure (1) Transfer tray loaded with brackets inserted and seated over the teeth.

Digital superimposition and measurement

The reference (M1) and post-bonding (M2) models were digitally superimposed using best-fit alignment to assess bracket placement accuracy. Positional differences were measured in millimeters across vertical, horizontal, and transverse planes, while angular deviations were recorded in degrees. Deviations were categorized as positive (+) for mesial, gingival, counterclockwise, and mesial-out shifts, and negative (-) for distal, incisal, clockwise, and mesial-in shifts.

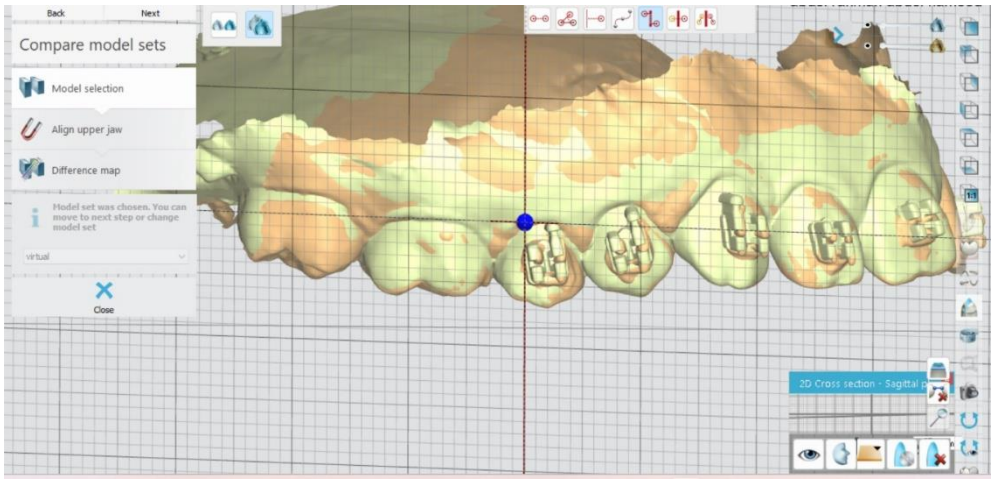

figure (1) *Superimposition of virtual and actual bonded upper arch*

3. RESULTS

Linear measurements

Mesio-distal (M-D) direction:

The (M-D) deviations were within the clinically acceptable range of 0.5 mm.

The (M-D) transfer error was 0.315 ± 0.025 mm. There was no statistically significant difference between (Incisors), (Canine), and (Premolars), where (p=0.765). 80 % of the bonded brackets showed more distal deviation (-) than the planned bracket position.

Occluso-gingival (O-G) direction:

The (O-G) deviations were within the clinically acceptable range of 0.5 mm.

The (O-G) mean transfer error was 0.366 ± 0.014 mm. There was no statistically significant difference between (Incisors), (Canine), and (Premolars), where (p=0.056), and 70 % of the bonded brackets showed more incisal deviation (-) than the planned bracket position.

Table (1) The mean and standard deviation (SD) values of linear measurements.

Variables	Linear measurements			
	Mesio-distal (M-D)		Occluso-gingival (OG)	
	Mean	SD	Mean	SD
	0.315	0.025	0.366	0.014

Table (2) The mean and standard deviation (SD) values of different teeth groups in linear directions.

Variables	Mesio-distal (M-D)		Occluso-gingival (OG)	
	Mean	SD	Mean	SD
Incisors	0.312	0.008	0.356	0.014
Canines	0.314	0.039	0.368	0.012
Premolars	0.318	0.020	0.374	0.011
p-value	0.765ns		0.056ns	

Angular measurements:

The angular deviations were within the clinically acceptable range of 2°.

Tipping

The mean transfer error was 1.632 ±0.091°. There was no statistically significant difference between (Incisors), (Canine), and (Premolars), where (p=0.077). 80 % of the bonded brackets showed more clockwise deviations (-) than the planned bracket angulation.

Rotation

The mean transfer error was 1.245 ±0.069°. There was no statistically significant difference between (Incisors), (Canine), and (Premolars), where (p=0.606). 60 % of the bonded brackets showed more mesial-in deviations (-) than the planned bracket rotation.

Table (3) The mean and standard deviation (SD) values of angular measurements.

Variables	Angular measurements			
	Tip		Rotation	
	Mean	SD	Mean	SD
	1.632	0.091	1.245	0.069

Table (4) The mean and standard deviation (SD) values of different teeth groups in angular directions.

Variables	Tip		Rotation	
	Mean	SD	Mean	SD
Incisors	1.578	0.108	1.230	0.039
Canines	1.630	0.054	1.244	0.074
Premolars	1.688	0.072	1.262	0.088
p-value	0.077ns		0.606ns	

4. DISCUSSION

Indirect bonding offers significant advantages over direct bonding, including improved accuracy, reduced chair time, enhanced patient comfort, and better clinical outcomes.[12, 13]

Several studies have been performed to evaluate the accuracy of bracket placement using the indirect bonding technique. These studies revealed that the IDB technique resulted in high transfer accuracy.[14]

This study adopted a fully digital workflow incorporating intraoral scanning and direct 3D printing to generate accurate, reliable virtual models while minimizing patient discomfort.[16] Even with the presence of fixed appliances, scanning produced models with no significant distortions.[15] The method enabled precise bracket evaluation through 3D superimposition, with independent analysis of each tooth–bracket pair to ensure measurement accuracy.

The present study used <0.5 mm for linear and <2° for angular differences as acceptable limits, based on standards from the American Board of Orthodontics.[24] The same values have been used in many recent studies to evaluate bracket transfer accuracy during model superimposition.[9, 11, 18, 19, 23] However, some authors recommended more strict ranges.[8, 22]

This study found mean transfer errors of 0.315 ± 0.025 mm in the mesio-distal direction, with 80% exhibiting a distal bias, and 0.366 ± 0.014 mm in the occluso-gingival direction, with 70% showing an incisal/occlusal bias. These linear deviations were higher than those reported by Faus-Matoses et al.[20], Park et al.[21], and Pottier et al.[11] whose studies using various CAD/CAM or 3D-printed systems generally reported mesiodistal and vertical errors below 0.2 mm.

This incisal/occlusal bias corroborates the outcomes of Niu et al.[23] and Castilla et al.[8] and explained their results by inadequate tray seating due to a minor lack of alignment between the bracket and the hard transfer tray, and by deficient vertical pressure on the tray during the light-curing procedure.

The present study reported clinically acceptable angular deviations in tipping and rotation, with mean errors of 1.632° ±

0.091° and 1.245° ± 0.069°, respectively. A directional bias was observed, as 80% of brackets exhibited more clockwise tipping and 60% showed greater mesial-in rotation than planned. However, these deviations were higher than those reported in previous studies by Park et al. [21], and Faus-Matoses et al.[20], which documented tipping and rotation errors below 1.2° and 0.8°, respectively.

Compared to these in vitro studies, the nature of this clinical trial, with its linked factors such as operator pressure, limited mouth opening, and patient movement, may be the cause of higher linear and angular transfer errors.

The data support the null hypothesis that there is no statistically significant difference between the virtually planned and bonded bracket positions using a hard resin tray.

5. CONCLUSION

Computer-aided indirect bonding with hard resin trays demonstrated accurate bracket placement in both linear and angular dimensions, with mean transfer errors falling within clinically acceptable limits. No statistically significant differences were observed among incisors, canines, and premolars in either direction

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