Original article

Comparison of bracket transfer accuracy between full arch and segmented arch indirect bonding trays fabricated by three-dimensional printing

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Abstract:

Objective: *To assess and compare the accuracy between full arch and segmented arch trays of bracket placement for indirect bonding fabricated by three-dimensional (3D) printing.* ***Materials and Methods:*** *Using digital software, orthodontic brackets were placed on scanned dental casts before full arch and segmented arch transfer trays were designed and printed by a stereolithographic 3D printer using elastic resin. The brackets were transferred onto the dental models by both types of transfer trays. Then, the final bracket positions were captured by a 3D model scanner on the dental models. The planned and actual model were superimposed to compare the difference of bracket positions. To analyze the data for significant differences between planned and actual bracket positions and between the two groups, nonparametric statistical analyses were used.* ***Results:*** *All significant differences in bracket position were less than 0.13 mm and 80% of these were less than 0.05 mm. No significant difference in bracket transfer accuracy between the directly printed full arch and segmented arch trays was found.* ***Conclusion:*** *For indirect bonding in orthodontics, the discrepancies of less than 0.5 mm of bracket transfer accuracy between the 3D printed full arch and segmented arch transfer trays are clinically acceptable. The choice of design can be individually tailored for each patient depending on factors such as chairside time, isolation control, degree of crowding, and ease of placement.*

Bracket Transfer Accuracy

the discrepancies from either method fell within clinically acceptable limits

Keywords: ● *Indirect bonding* ● *Bracket transfer* ● *Bracket accuracy* ● *3D printing*

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นิพนธ์ต้นฉบับ

การเปรียบเทียบความแม่นยำของถาดติดเครื่องมือจัดฟันแบบเต็มขากรรไกรและบางส่วนของขากรรไกรซึ่งสร้างโดยเครื่องพิมพ์สามมิติ

โสภิต รัตนสุมาวงศ์ ศรินนา ตันติธนเศรษฐ์ พีรพงศ์ สันติวงศ์ และ สมชาติ เราเจริญพร

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บทคัดย่อ

การวิจัยนี้มีวัตถุประสงค์เพื่อประเมินและเปรียบเทียบความแม่นยำของถาดติดเครื่องมือจัดฟันแบบเต็มขากรรไกรและบางส่วนของขากรรไกรซึ่งสร้างโดยเครื่องพิมพ์สามมิติ การดำเนินการประกอบด้วยการใช้ซอฟต์แวร์ในการวางตำแหน่งเครื่องมือจัดฟันบนโมเดลฟันจำลอง ออกแบบถาดติดเครื่องมือจัดฟันแบบเต็มขากรรไกรและบางส่วนของขากรรไกร ประมวลผลเป็นไฟล์ภาพสามมิติ ชนิดไฟล์ STL จากนั้นนำไปพิมพ์ด้วยเครื่องพิมพ์สามมิติ เมื่อได้ถาดติดเครื่องมือจัดฟันทั้ง 2 แบบแล้ว นำไปติดเครื่องมือจัดฟันบนโมเดลฟันจำลอง และสแกนอีกครั้งด้วยเครื่องสแกนโมเดลสามมิติ ในที่สุดทำการประมวลผลการซ้อนทับระหว่างไฟล์ภาพการติดเครื่องมือจัดฟันในซอฟต์แวร์ และไฟล์ภาพการติดเครื่องมือจัดฟันโดยใช้ถาดติดเครื่องมือจัดฟัน โดยประเมินความแตกต่างของไฟล์ภาพ ด้วยสถิติทดสอบที ที่ระดับนัยสำคัญทางสถิติที่ 0.05 และเปรียบเทียบค่าความแตกต่างเฉลี่ยระหว่างถาดติดเครื่องมือจัดฟันทั้ง 2 แบบ ด้วยสถิติทดสอบครัสคัลและวอลลิส ผลการวิจัยพบว่า การซ้อนทับระหว่างไฟล์ภาพของเครื่องมือจัดฟันมีความแตกต่างน้อยกว่า 0.13 มิลลิเมตร โดยมากกว่าร้อยละ 80 มีค่าน้อยกว่า 0.05 มิลลิเมตร และไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างถาดติดเครื่องมือจัดฟันทั้ง 2 แบบ สรุปผลการวิจัยการเปรียบเทียบความแม่นยำของถาดติดเครื่องมือจัดฟันแบบเต็มขากรรไกรและบางส่วนของขากรรไกรโดยเครื่องพิมพ์สามมิติ มีความแม่นยำในระดับที่สามารถยอมรับได้ทางคลินิกคือน้อยกว่า 0.5 มิลลิเมตร การเลือกใช้งานของถาดติดเครื่องมือทั้ง 2 แบบ อาจขึ้นกับปัจจัยอื่นๆ ร่วมด้วย เช่น ความยากง่ายในการติดเครื่องมือจัดฟัน การเรียงตัวของฟัน เวลาข้างเก้าอี้ของทันตแพทย์ และความสามารถในการกันน้ำลาย

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Introduction

Success in orthodontic treatments depends on achieving ideal bracket positioning as this has been found to minimize overall treatment time by reducing the orthodontic arch wire bending and repositioning the brackets.[1] As an alternative to direct bonding, the indirect bonding technique was introduced by Silverman, et al in 1972.[2] For this technique, orthodontic brackets are first placed in desired positions on dental casts before fabricating a transfer device on these casts to be used to bond the brackets in the same configuration on the patient's dentition.

Indirect bonding is an effective method due to clear visibility during bracket positioning, shorter chair time, and better patient comfort. Though it is believed to have higher accuracy than direct bonding, indirect bonding is more technique sensitive and consumes more laboratory processing time[3,4]. Before bonding can be carried out, intraoral scans or impressions need to be taken and a separate appointment would usually have to be made. For the fabrication of bracket transfer trays, various methods and materials have been developed such as vacuum-formed thermoplastics, silicone impression materials, and a combination of both[5].

Since the 1980s, computer-aided design and computer-aided manufacturing (CAD/CAM) have expanded into the field of dental research. Recently, CAD/CAM technology based on additive manufacturing is leading the trend in digital dentistry[6], where three-dimensional (3D) printers based on stereolithography, digital light processing, and polyjet printing of ultraviolet light-polymerized resin are most widely used. In orthodontics, 3D printing has been so far been utilized for clear aligner therapy, laboratory-fabricated indirect bonding trays, customized brackets with patient-specific torque, and robotically generated arch wires[7].

With CAD/CAM technology, the steps in the fabrication of indirect bonding transfer trays began to change. Initially, digital files of the patient's dentition from either intraoral scanning or 3D scanning of dental models are obtained. With digital processing software, orthodontic brackets are set up in the desired positions before these tooth models with brackets are manufactured by a 3D printer. The transfer tray is then manually made with the thermoplastics or silicones in the laboratory. This process, while partially digital, still has the potential to introduce errors from many steps.

The latest developments in 3D printing have introduced resins with suitable properties for use as indirect bonding trays to be directly printed after being designed in the digital software. This eliminates the manual laboratory fabrication step of the former method.

Though the published studies on this newer method are still limited so far, the results generally show that directly printed trays are equally or more accurate than the older methods within clinically acceptable thresholds[8,9].

While indirect bonding trays are usually fabricated as a single piece for each arch, clinicians may opt to segment the trays in certain situations. Though there are no strict guidelines about deciding upon tray segmentation, isolation control and ease of tray placement are some examples where this might be done[10].

Significance

Variation of design in indirect bonding tray provide wide range of accuracy. In order to facilitate clinicians to make an informed decision about the most suitable design for their practice, it is desirable to explore the transfer accuracy between different designs of transfer media. Full arch transfer tray may be suitable in well align teeth and good isolation control while segmental arch transfer tray allows more adaptation of tray placement in crowding teeth. To date, accuracy comparisons between full arch and segmented arch trays have not been widely explored.

Research Objective

The aim of our study was to evaluate and compare the accuracy of bracket placement between full arch and segmented arch transfer trays prepared by 3D printing for indirect bonding.

Null Hypothesis

There is no statistically significant difference in accuracy of bracket placement with full arch and segmented arch transfer trays prepared by 3D printing for indirect bonding.

Materials and methods

Working Stone Models

Using silicone molds of maxillary and mandibular models with good tooth alignment, parabola dental arch form, Angle's classification I, normal overjet and overbite (Nissin Dental Product INC.) as the master model template, ten sets of identical orthodontic stone models were prepared (Pink stone, Type IV, Velmix) and divided into two groups of five sets each.

Model Scan and Bracket Placement

All master models were scanned by a 3D model scanner (D2000 3Shape, Camera 2x5MP, Accuracy ISO 12836 10 μm, scan speed 40 sec, standard scanning strategy) and bracket placement was done in digital software (3Shape Ortho Analyzer, 3Shape Dental Systems, Copenhagen, Denmark). American Orthodontics Mini Master with a Roth 0.022" slot brackets were placed from the right second premolar to the left second premolar in each dental arch.

Fabrication of Bracket Transfer Media

The full arch and segmented arch transfer trays were designed in 3Shape Appliance Designer Software (Figure 1), then directly printed using elastic resin (Elastic resin 50A, Form2, Formlabs Inc. US) in a stereolithographic 3D printer (Form2, Formlabs Inc. US). Full arch transfer tray was outlined from left to right second premolars. Segmental arch transfer tray contains three pieces per one arch which are anterior segment (incisors and lateral incisors), left and right posterior segments (canines and premolars).

Bracket Transfer and Re-scan

By using the 3D printed trays, bracket bonding was carried out on the stone models with light-cured adhesive (Transbond™ XT, 3M Unitek, Neuss, Germany), after which they were covered with a thin layer of scan spray (CEREC® Optispray, Sirona Dentsply, Munich, Germany) to reduce reflections from the metal brackets. These bonded stone models were then rescanned using the

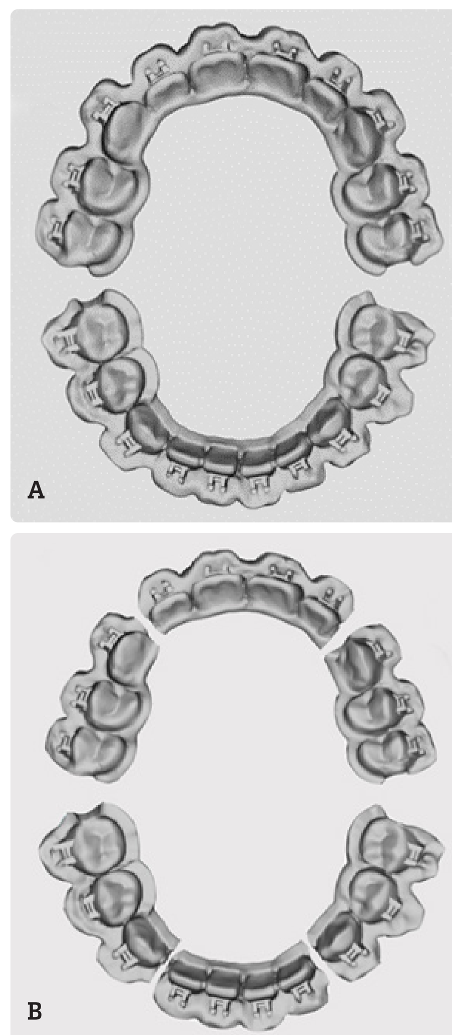

Figure 1 Digital preparations for bracket transfer media. **A)** Directly printed full arch transfer trays **B)** Directly printed segmented arch transfer trays

Table 1 Definitions of the four points of measurement

Point 1	Mesio-occlusal bracket wing, disto-cervical edge
Point 2	Disto-occlusal bracket wing, mesio-cervical edge
Point 3	Mesio-cervical bracket wing, disco-occlusal edge
Point 4	Disto-cervical bracket wing, mesio-occlusal edge

Table 2 Mean Differences in Bracket Position between Template and Experimental Models

	Full arch transfer tray			Segmented arch transfer tray		
	Incisor	**Canine**	**Premolar**	**Incisor**	**Canine**	**Premolar**
Upper						
Horizontal	0.044 ± 0.052	0.034 ± 0.017	0.033 ± 0.018	0.030 ± 0.009	0.030 ± 0.017	0.032 ± 0.011
Vertical	0.037 ± 0.010	0.036 ± 0.021	0.036 ± 0.022	0.032 ± 0.008	0.036 ± 0.022	0.074 ± 0.070
Transversal	0.065 ± 0.066	0.035 ± 0.016	0.045 ± 0.043	0.057 ± 0.057	0.052 ± 0.038	0.047 ± 0.048
Lower						
Horizontal	0.025 ± 0.010	0.038 ± 0.010	0.054 ± 0.065	0.030 ± 0.017	0.039 ± 0.010	0.051 ± 0.060
Vertical	0.035 ± 0.011	0.036 ± 0.010	0.059 ± 0.046	0.037 ± 0.014	0.029 ± 0.010	0.053 ± 0.042
Transversal	0.032 ± 0.012	0.037 ± 0.026	0.034 ± 0.024	0.032 ± 0.013	0.059 ± 0.084	0.040 ± 0.023

same model scanner (D2000 3Shape, Camera 2x5MP, Accuracy ISO 12836 10 μm, scan speed 40 sec, standard scanning strategy) for further analysis.

Measurements

The scans of the template models before bracket bonding were uploaded in .stl file format as 'CAD body element', whereas the experimental models with bonded brackets were uploaded as 'mesh actual element'. Measurements and superimpositions were carried out using digital software (GOM Inspect Version 8 SR1, GOM GmbH, Braunschweig, Germany), with millimeters (mm) set as the standard unit of measurement. The differences at four points at the corners the inner wings of each bracket were calculated (Figure 4, Table 1), where for each point, X-axis, Y-axis and Z-axis values were recorded to be mesio-distal (horizontal), occluso-cervical (vertical), and bucco-lingual (transverse) positions respectively.

Superimpositions were carried out by selecting 'Local Best-Fit 'to eliminate deviations between the models and brackets, and interpreted by color surface comparisons ranging from green-yellow-orange-red representing 0.1-0.2-0.3-0.4-0.5 mm discrepancies.

Statistical analysis

The mean differences of the discrepancies between the template models and experimental models were calculated by using non-parametric one sample t-tests, with a significance level set at $p < 0.05$. Comparison of the mean differences between the two groups was performed by using Kruskal-Wallis tests. (Statistical Package for Social Sciences v.22, IBM Corp, New York, U.S.A.) The method error between the first and second measurements was determined using Dahlberg's formula.

Results

Altogether, the transfer accuracy of 200 brackets were analyzed, with 50 brackets per method and four points measured per bracket. The greatest mean differences for any point on the brackets were not more than 0.074 mm, found in the vertical dimension of the maxillary premolar brackets using the segmented trays. The smallest mean differences were 0.025 mm, occurring in the horizontal dimension of the mandibular incisor brackets using the full arch trays. (Table 2)

For both full arch and segmented arch trays, most of the significant discrepancies in bracket position occurred

Table 3 Significant mean differences in bracket position between template and experimental models

Full arch transfer tray			Segmented arch transfer tray		
Tooth	**Direction**	**Mean Difference**	**Tooth**	**Direction**	**Mean Difference**
11	B-L	0.034	11	M-D	0.022
12	O-G	0.022	24	O-G	0.128
13	O-G	0.028	25	O-G	0.118
24	M-D	0.009	31	O-G	0.023
25	O-G	0.019	44	B-L	0.039
	B-L	0.095			
31	M-D	0.018			
	O-G	0.020			
35	O-G	0.059			
41	O-G	0.014			
42	M-D	0.025			
	B-L	0.020			

All data shown were statistically significant at $p < 0.05$

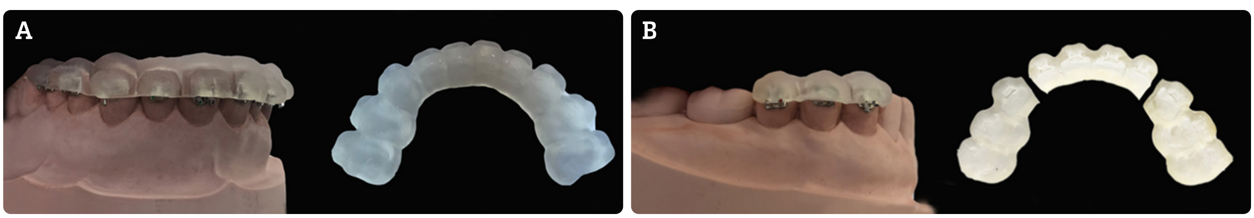

Figure 2 Bracket transfer trays **A)** directly printed full arch, **B)** directly printed segmented arch

in the vertical axis. The maxillary and mandibular anterior teeth were most affected for the full arch trays, while the significant mean differences found for the segmented arch group tend to affect the premolar teeth. Overall, the significant discrepancies in either group were not more than 0.13 mm in all dimensions, of which about 80% were less than 0.05 mm. (Table 3)

The method error calculated using Dahlberg's formula was 0.0004 and 0.0001 mm for the full arch and segmented arch groups, respectively.

For color surface comparisons of the superimposed template and experimental models, most areas of each bracket appeared in green, interpreted as deviations of less than 0.5 mm. (Figure 2)

From the results of the Kruskal-Wallis tests, no statistically significant difference in bracket position discrepancies in any dimension between the directly printed full arch and segmented arch transfer methods was found (results not shown). Therefore, the null hypothesis is accepted.

Discussion

Most studies on indirect bonding in orthodontics aimed to compare indirect bonding with direct bonding in terms of bond failure, bond strength, clinical efficiency, as well as accuracy of placement[11,12]. A common concern is that indirect bonding is more time consuming, which affects its cost-effectiveness and clinical efficiency. Though indirect bonding inevitably requires more time in the laboratory, the actual chairside time for the bonding appointment is much less for the indirect technique[11].

Apart from the duration of the bonding appointment, indirect bonding does not negatively impact the bonding failure rates, total treatment time, or number of appoint-

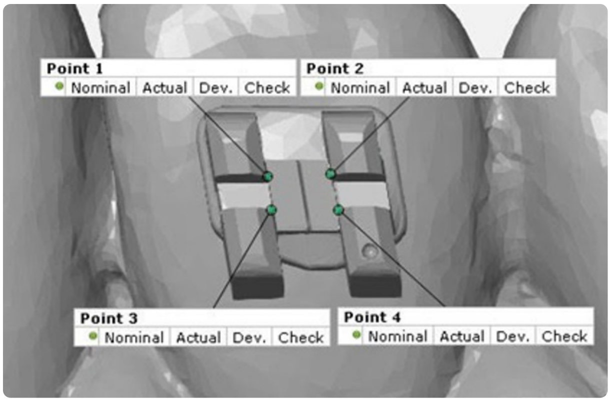

Figure 3 Points at the corners the inner wings of each bracket

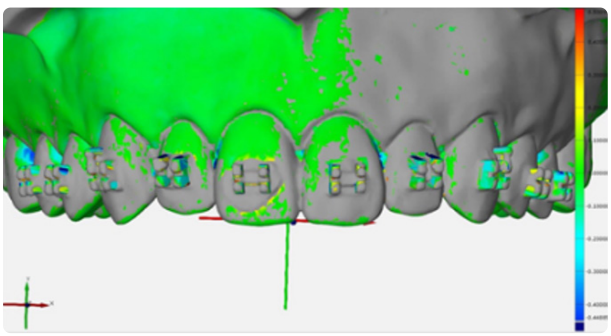

Figure 4 Superimposition between template and experimental models with local best-fit

ments[12]. Similar outcomes of orthodontic treatment can also be achieved regardless of the bonding technique applied[13].

In general, indirect bonding techniques have been shown to have high positional accuracy within clinical limits of 0.5 mm for linear discrepancies, and 3° for angular measurements[14,15].

Previously, bracket transfer trays for indirect bonding were fabricated from vacuum-formed thermoplastic sheets or polyvinylsiloxane (PVS) trays based on manually simulated bracket positions on plaster casts. PVS trays have been reported to be more dimensionally accurate while thermoplastic trays tend to be thicker faciolingually, with significant discrepancies of about 0.1 mm found in the vertical and horizontal planes[16,17].

Digital dentistry is gradually making its mark in various aspects from diagnosis and treatment planning to appliance fabrication and also practice management[18]. The benefits of storing digital data include the ease of transportability, sharing of data, and elimination of the burden of storage faced by many practices[19]. With digital software and CAD-CAM technology, the range of materials and methods used for indirect bonding transfer media has expanded.

By designing the transfer trays using digital software and then directly printing them, we believe that this can save laboratory time[20]. Besides, by cutting down the number of processing stages, the risk of cumulative errors can also be potentially reduced.

In our study, we were interested to find out whether segmented arch trays would affect the accuracy of bracket transfer compared to full arch trays. Though no significant difference was found between the two groups, the segmented arch trays tend to show fewer significant discrepancies in all dimensions. Interestingly, however, the greatest mean differences in tooth position of 0.074 mm were found in the vertical dimension of the maxillary premolar brackets using the segmented trays, while the smallest mean differences of 0.025 mm occurred in the horizontal dimension of the mandibular incisor brackets using the full arch trays. (Table 2 and 3)

It was our assumption that the flexibility of segmented arch trays could provide better adaptation of the tray and brackets. This would lead to more accurate bracket transfer and decrease the incidence of bond failures in treatment. From the statistical analysis, the null hypothesis of our study was accepted as the accuracy of the 3D printed full arch elastic resin transfer trays was equal and comparable to that of segmented arch trays. Our results are in agreement with two previous studies by Huang et al and El Sebaay, et al[10,21].

When comparing directly printed trays with traditional silicone trays, Pottier, et al who fabricated full arch 3D-printed trays using elastic resin found that their precision is still slightly inferior to silicone trays for all linear and angular measurements, especially around the terminal regions. They inferred that it could be due to printing errors especially in the transverse direction[22]. Nevertheless, the discrepancies from either method fell within clinically acceptable limits which indicates that 3D printed trays are a reliable replacement for the manually fabricated trays.

The Objective Grading System of the American Board of Orthodontics suggests that tooth alignment deviations of 0.5 mm are the acceptable threshold[23]. Using this value as a guide, over 90 percent of discrepancies in our study were less than 0.08 mm, which falls safely within this clinically acceptable threshold. A recent study by Duarte, et al also reported similar differences in bracket positions using directly printed trays ranging from 0.04 to 0.13 mm, and that using digital technology also offered good reproducibility in bracket positions[24].

To rule out possible variables such as dental arch form and tooth shapes, models with ideal tooth alignment were used as the main template for assessment. Method errors of less than 0.042 for all groups confirmed the reliability of the points chosen for bracket position measurement.

Within the confines of our study, we can suggest that segmented arch transfer trays could offer a beneficial alternative for cases where full arch transfer trays would be unfeasible, or to reduce the immediate bracket failure rate[21], though they may be slightly more time consuming to fabricate[10,21]. Menini et al has reported successful uses of full arch trays even in patients with severe crowding[25]. Considering that full arch trays consume equal or even less chairside time compared to segmented trays[10,21], they can be the first choice in cases where bonding is straightforward and can be done for the entire arch simultaneously.

As our research was only conducted in vitro, it is not without its limitations. Other parameters of interest which should be investigated in future studies would include cost effectiveness, varying tray thickness, and even patient comfort when using different materials for the direct 3D printed transfer trays, especially when applied in real clinical situations.

Conclusions

The bracket transfer accuracy of both directly printed full arch and segmented arch transfer trays were not statistically different, and both were clinically acceptable for indirect bonding of orthodontic brackets. However, the segmental arch trays tend to show fewer significant discrepancies in all dimensions.

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