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لـلـطـب و الـعـلـوم الـصـحـيـة

MOHAMMED BIN RASHID UNIVERSITY
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ACCURACY OF THREE-DIMENSIONAL PRINTED GUIDE PLATES FOR INDIRECT BRACKET PLACEMENT: ONE PIECE VERSUS SEGMENTED, AN IN VITRO SUDY

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ABSTRACT

Accuracy of three-dimensional printed guide plate for indirect bracket placement: one-piece verses segmented, an in Vitro study

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Co-supervisor: Dr. Samira Diar-Bakirly

Background: An accurate placement of brackets is a key element of the comprehensive treatment process of orthodontics to achieve an ideal occlusion. Orthodontic brackets can be directly placed on tooth surfaces or indirectly.

Aim: To compare the accuracy of indirect bonding techniques in moderate, and severe crowding cases using three-dimensional printed one-piece transfer tray and segmented trays. Digital models with virtual brackets were considered as the control group. Four points were selected in each tooth to perform the analysis. From the midpoint of each bracket to the mesial margin (CM= center mesial), distal margin (CD =center distal), occlusal/ incisal margin (CI= center Incisal/occlusal) and gingival margin (CG= center gingival). Shapiro-Wilk was used to test the normality of continuous variables. The Mann-Whitney test, Kruskal-Wallis H test was used. A P-value of less than 0.05 will be considered significant in all statistical analyses.

Results: There were statistically significant differences between models with moderate crowding bonded using full, segmented transfer trays and control for CD12, CD21, CI25 ($P < 0.001$). While the rest of the measurements showed no significant differences between models with moderate and severe crowding bonded using full, segmented transfer trays and control (P=1.0).

Conclusion: The one-piece and the segmented indirect 3D printed transfer trays are accurate in the severe and moderate malocclusion.

DEDICATION

I would like to dedicate my research to:
The one person who has made this all possible has been my mother, she has been a constant source of support and encouragement and has made an untold number of sacrifices for the entire family, and specifically for me to continue my postgraduate. she taught me to fight and work hard pursuing my dreams and to never underestimate my capabilities. She is a great inspiration to me. Hence, great appreciation and enormous thanks are due to her.

My beloved sisters and brothers. Thank You for believing in me. I wouldn't have made it without your support. Thank you for all the sacrifices you made for me.

My nephews Abdulla, Saif, Khalid and Maktoum thank you for your unconditional love.

DECLARATION

I declare that all the content of this thesis is my own work. There is no conflict of interest with any other entity or organization

Name: Bayan Alyammahi

Signature:

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1. INTRODUCTION

Although malocclusion is neither a serious or life-threatening condition, orthodontic care has long been in high demand (1, 2). A variety of occlusal indices have been developed to help prioritize the treatment of malocclusion based on severity of malocclusion and the possible damage to oral health if left untreated (3-5). There are numerous problems related to malocclusion, including appearance discrimination, oral function difficulties, such as jaw movement difficulties caused by muscle imbalances, pain, difficulties with mastication, swallowing, and speech, and caries and periodontitis (6).

Accurate placement of orthodontic brackets is a crucial stage in the comprehensive orthodontic treatment (7) to achieve the ideal occlusion described by Andrew's six key principles (8, 9). Correct alignment of crowns and roots, and level marginal ridges are hallmarks of a well-done orthodontic procedure. The position of the bracket on the crown affects the tooth's final tip, torque, height, and rotation with preadjusted brackets (7, 10). Inaccurate bracket placement results in inaccurate tooth position. This will require several archwires modifications and several artistic bends during the finishing stage of orthodontic treatment resulting in a longer treatment period or a less than ideal final occlusion (11).

Placing orthodontic brackets on tooth surfaces can be done directly or indirectly. This is a multiple steps process that requires special attention to details such as the bonding technique, quality of the bonding materials, and skills of obtaining a dry working field. Moisture control is an essential step for successful bracket placement because moisture contamination of the pretreated enamel surface may cause weakening of the bond strength and failure of orthodontic treatment and the fact that tooth position may not be accessible because of severe crowding may elongate the time needed for direct bonding technique. All these factors may reduce the accuracy of this technique (12). It has been shown that drawbacks related to moisture control, chairside time, and bracket positioning are significantly minimized when using Indirect bonding technique (13).

In 1972, Silverman *et al*. developed indirect bonding (IDB) to avoid the drawbacks of the direct bonding technique and to enhance the patient experience during brackets placement (14) . All procedures were carried out manually, which is time consuming until digital workflows were introduced into the IDBS (15). The indirect bonding procedure consists of two stages, the laboratory stage and the clinical stage (12). After the orthodontic models are obtained from patients, brackets are attached to study models in the laboratory phase and then fitted to the tooth surface with the use of a customized tray in the clinical phase (16, 17). Brackets are manually fitted on stone or resin models on the model in the traditional indirect bonding technique, and then a transfer tray from silicone-based materials, vacuum-formed thermoplastic sheets, or a combination of both (14, 18-21) .

A silicone-based tray is reported to have better precision than a thermoform tray (22). In simple procedures, thermoformed transfer trays can be used (15), but the tray material, a flexible sheet, can be easily deformed during removal, making it difficult to reuse. A flexible tray may also affect the placement of the tray intraorally, which requires a firm and precise pressure (23).

Several digitalized indirect bonding systems emerged lately as an outcome of the recent advances in the 3D imaging technology and the development of new software programs (24-26). Using these new software programs enable the clinician to simulate the tooth movement, align the teeth into their ideal position, virtually position the orthodontic brackets, design, and print the customized transfer trays that will be used during the indirect bonding technique (27-30). The process of digital workflow of indirect bonding and virtual planning requires the use of a highly advanced software capable of simulating the brackets positioning on the digital models created from intraoral scans. These software programs involve a built-in bracket library that include a wide variety of bracket sizes, designs, and different bracket brands where the clinician can pick and choose the right bracket size that match the physical brackets to be used. The software programs can also provide visualizing tools that allow the clinician to rotate and manipulate the digital models in 360 degrees and previewing the tooth from multiple perspectives to ensure the most accurate brackets placement(21).

The digitally positioned brackets can then be transferred using one of the following approaches. The first approach would involve printing the whole virtual set up including the digital model with brackets that were virtually placed on the teeth surfaces. Then the bracket transfer trays can be fabricated in the lab using silicone- or vacuum-formed materials (15, 30). The second approach would involve designing the bracket transfer trays or a single jig virtually. Then these virtual transfer trays can be printed using a biocompatible resin, without the need for an intermediary physical bracket transfer model (30-32). In either approach, once the bracket transfer trays have been fabricated, they can be filled with the physical brackets, which are then transferred to the patient's teeth for concluding the indirect bonding process. There are several advantages of using a complete virtual set up as described in the second approach. This approach would significantly reduce human errors by eliminating a number of manufacturing stages and materials needed for fabricating the transfer trays in the lab and allows a rapid development process and quick turnaround time (27, 31, 33). Up-to-date, there is a lack of information about the accuracy of indirect bonding technique by using a one-piece transfer tray versus multiple segmented transfer trays in cases with moderate versus severe crowding.

2. REVIEW OF THE LITERATURE

2.1. Orthodontic Brackets: evolutions

The concept of Edgewise appliance was introduced by Edward Angle, the "father of orthodontics" in the Early 1900s, Angle made considerable effort to improve the dental appliances that he used and sold through dental supply houses. Both Angle's ribbon arch and pin-and-tube appliances were difficult to use. Edward Angle felt compelled to create something that was better than anything available during the mid-1920s (34). At that period of time, he was the first to use an orthodontic bracket with a horizontal slot in his standard edgewise appliance (35). For each tooth in the arch, a bracket with a uniform slot and base was used in the standard edgewise system. The morphology of each tooth type necessitate numerous compensatory bends in the arch wire when using standard edgewise appliances to achieve ideal tooth alignment (36) . This was time-consuming, error-prone, and technique-sensitive process. A straight-wire appliance was developed and introduced in the 1970s by Lawrence Andrews, who designed tooth-specific brackets with built-in torque, tip, and in-out compensations (37). Preadjusted appliances were designed so that there was no need to modify the wire to achieve proper alignment with a straight wire since variation is built into the brackets. Ideally the brackets should be positioned in the center of the clinical crown, in line with the facial axis (long axis) of the clinical crown to properly transfer the desired built-in features from the brackets to the teeth. Although many changes were implemented to Andrews' original straight-wire over the years, the preadjusted appliance used today still depends heavily on the ideal bracket position to achieve ideal tooth movement(38).

2.2. Bracket positioning

With preadjusted orthodontic appliances, bracket placement is crucial for effective and efficient treatment. The placement of brackets in the ideal position at the beginning of treatment minimizes the time and expense of repositioning brackets midway through treatment and bending archwires to correct marginal ridge discrepancies, rotations, and root parallelisms (36, 39). It is crucial that brackets are placed correctly in all planes of space, because any change in the position can translate to a different tooth movement. The positioning error of a bracket in one dimension can have an adverse effect on the tooth position in the other dimensions; For example, positioning the bracket vertically incorrectly can change the tooth's torque and buccolingual position (40). Due to the fact that brackets work simultaneously through the wire, one poorly positioned bracket can affect adjacent brackets, and the effect is multiplied when more than one bracket is misplaced, preventing the case from being finished efficiently (35).

2.3. Bonding methods: Direct and Indirect bonding

2.3.1. Direct bonding

Placing orthodontic brackets on tooth surfaces can be done directly or indirectly bonding methods. A clinician determines the bracket position intraorally during the direct bonding procedure (6). Direct bonding requires the clinician to accurately visualize the correct mesio-distal position, vertical position, and slot angulation of the bracket while working inside the mouth (39). Direct bonding is much more efficient than the indirect bonding whenever a single bracket must be repositioned. Direct bonding presents a challenge in that the dentist must judge the correct position for the attachment and must place it quickly and accurately to the correct position.

The opportunity for precise bracket measurements or detailed adjustments is less than it would be at a laboratory bench. Therefore, direct bonding is generally acknowledged not to be as accurate as indirect bonding when it comes to bracket placement. Direct bonding, however, is easier, faster (especially when just a few teeth require bonding), and more cost-effective (because laboratory fabrication is eliminated) (6).

Direct Bonding procedure: thoroughly clean all enamel surfaces of the teeth to be bonded with a polishing brush and pumice paste before bonding them. Following a thorough rinse with water, dri-angles, a lip expander, and a double saliva ejector are inserted. 37 percent phosphoric acid was applied for about 90 seconds to condition the teeth surface. The etched tooth surface has a chalky or frosted appearance if dried. A thin layer of sealant applied to the tooth surface and cured. For bonding, composite material is applied into the mesh on the back of the bracket, and pressed to place on the tooth surface, the excess is removed from around the bracket and then light-cured (6, 41). Chemically activated resins are now used less often than light-cured resins since light-cured materials have more flexibility in working time and have higher bond strengths.

2.3.2. Indirect bonding

Silverman et al. first introduces indirect bonding in 1972. It involves attaching brackets on a model of the dentition and then transferring those brackets to the patient’s teeth with a custom tray or jig (14) using an unfilled methyl-methacrylate based adhesive (BisGMA). As a result of the work of Silverman and Cohen, this technique was improved by using a mesh base and ultraviolet (UV) cured BisGMA resin in 1975 (42). Since the teeth in indirect bonding can be inspected from any angle without being restricted by the cheeks or saliva, it is possible to place brackets with greater precision than direct bonding. Clinicians can perform indirect setups in the office lab, but in many cases now, stereolithographic casts are made using impressions sent to a company that also produces digital casts for diagnostic purposes. For indirect bonding, a quick alginate impression, poured fairly rapidly in the office lab, is sufficient to give an accurate working cast, but for digital scanning later, more stable impressions are needed (6).

Compared to direct bonding, traditional indirect bonding requires less clinical chair time for the orthodontist. This result in a more comfortable and quicker appointment for the patient and efficient use of doctor time (43-45). The drawback of this is, however, the increased time spent in the laboratory steps, such as making models, brackets positioning, and trays fabrication.

Indirect bonding is done in two stages: Clinical stage and laboratory stage. In the clinical stage, perform a dental prophylaxis followed using high-quality alginate to take impressions of the upper and lower arches to obtain a dental cast with type IV dental stone. Therefore, dental casts must be carefully examined to ensure they are free of imperfections (both positive and negative bubbles). A surface flaw can prevent brackets and trays from fitting properly to the teeth when the latter are inserted into the mouth. It is additionally important to wait for the stone to completely solidify and dry. In the laboratory stage, on the previously obtained cast draw the bracket positioning guidelines.

The first step is to determine the long axis of the tooth on the center of its crown with a black pencil, and a panoramic radiograph is used as an auxiliary method to increase accuracy and observe tooth angulation. Identify the mesial and distal marginal ridges on the buccal surface of premolars and molars and join them together and this line will represent the height of posterior teeth marginal ridges and establish the depth of occlusal contact. Then with the black pencil draw the bracket slot height starting from the first molar and this position depends on the type of malocclusion and the anatomical shape of teeth.

Apply a thin layer of separator mixed with water in a ratio of 1:1 over the cast teeth surfaces, and wait for at least 20 minutes to dry completely. Apply light-cured adhesive material to the bracket base and position it over the cast surface over the drawn guide lines, then use a light-curing unit to cure the adhesive material according to the manufacturer's instruction. Fabricate the transfer tray using a vacuum former, thermoform a 1-mm thick sheet of Ethylene Vinyl Acetate over the cast. As soon as the sheet reaches 10 to 12 mm of distortion after heating, according to the manufacturer's instructions, the sheet can be shaped. Using a scissors trim the excess material and spray silicone over the tray to enable it to be separated later from the second tray that is made from a more rigid material. Thermoform a 1.5 mm thick sheet of polyethylene Trephthalate Glycol that should be 2 to 3 mm above the cervical margin of teeth on both buccal/labial and lingual/palatal surfaces. Soak the working cast in a warm water to facilitate the removal of the transfer tray (20). The teeth then are isolated, etched and chemically cured two-paste resin/ light-cured resin that is applied on the etched enamel and bracket. Then carefully insert the tray over teeth without applying exaggerated pressure. Once the resin has completely set, the trays are carefully removed, leaving the brackets bonded to the teeth (6).

Transferring brackets to teeth with precision and sufficient bond strength is a critical aspect of the indirect bonding method, which is largely determined by the material selection and method of making the transfer tray (16).There are various materials used for indirect bonding trays. Traditionally, indirect bonding has been carried out using silicone materials, vacuum-formed thermoplastic sheets or a combination of materials (14, 18-21, 36, 38). Using a soft material exclusively can lead to inaccurate bracket positioning and high bond failure rates as a result of poor fitting (22). Thermoplastic ethylene-vinyl acetate copolymer, in the form of a stick ("hot glue") or in thermoforming sheet is an example of soft material. Transfer trays made of thermoformed sheets can be easily used in simple procedure(15) , but their flexible material is prone to deformation during removal, making them unreusable. The flexibility may also impact the positioning of the tray intraorally, which requires firm and precise sitting. Materials made of silicone and silicone sheets combined with thermoplastic sheets have also been developed (23). In a study performed by Castilla et al., they found that silicone trays offered similar accuracy to thermoformed trays, but the silicone trays presented a higher degree of consistency of bracket placement (22).

2.4. 3-D printer and technology

With the advent of digital technology, 3D-models are widely used for the diagnosis and treatment planning. It has been shown that virtual occlusal records are accurate in terms of contact size and location in virtual bite registrations using intraoral scanners (46). Additionally, digital indirect bonding allows superimposing of patient's tomographic image on digital models to view dental roots and determine bracket position accurately (47). Digital transfer trays for indirect bonding, virtual setups, and 3D- printing models are among the other innovations (48-50).

The bracket position can now be planned virtually and bonding tray can be designed on a computer, 3D-printed and adapted to the patient's malocclusion (51). Prior studies have compared the results of digital indirect bonding for its efficiency and precision with the virtual setup or with other bonding methods, which in general considered an efficient technique (28, 32, 52-54).

Direct bonding and traditional indirect bonding methods have been compared for their time requirements with digital indirect bonding (12, 55). A randomized controlled trial by Czolgosz *et al.* compared the chair time and total operating time of indirect bonding using 3D-printed CAD/CAM trays versus direct bonding (12).Their finding showed that the clinical chair time was dramatically reduced by using the CAD/CAM trays by four minutes per half-mouth. However, it took 11.5 minutes longer for the total procedure, including digital bracket placement, than direct bonding.

2.5. Brackets Transfer Accuracy

With indirect bonding, the most critical consideration is the transfer device's ability to reliably transfer bracket position to the denture. For years, studies have relied on 2D or photographic methods to determine transfer accuracy (16, 22). New advances in 3D imaging, digital intraoral scanning, and 3-D superimposition strategies, however, have enabled bracket positioning to be compared with six degrees of freedom. Recent studies have evaluated bracket transfer accuracy using 3D superimpositions. Recent studies have evaluated bracket transfer accuracy using 3D superimpositions (23, 56, 57). Although the methods vary from study to study, the general approach is the same: digital intraoral or cone-beam computed tomography (CBCT) scans of the models or dentition are used to produce two sets of digital models. Two models are typically produced. One represents the "setup", or planned position of the brackets, and the other represents the bracket position on the teeth or models after indirect bonding.

3. AIM

To compare the accuracy of indirect bonding techniques in moderate, and severe crowding cases using three-dimensional printed one-piece transfer tray and segmented trays.

4. MATERIALS AND METHODS

4.1.Subjects and Sample Selection

The sample of this study consisted of 80 upper dental digital models. We selected two stone models one with moderate crowding of 6-7mm and the one with severe crowding of 10 mm (Cobourne and DiBiase 2010) from an un-identified patients and calculated using London space analysis. Dental models classified into two groups according to the amount of space deficiency. Group 1 (moderate crowding) included 40 digital models with a space deficiency of 6-7 mm, and Group 2 (severe crowding) included 40 digital models with a space deficiency of 10 mm. Dental models with poor quality, primary or mixed dentition, broken teeth, and models with defects or restorations that involve the labial/buccal tooth surfaces were excluded from the study. Model with severe rotation, overlapping anterior teeth, and partially erupted teeth was included in the severe group. Digital models with virtual brackets were considered as the Gold standard (control group). The process of creating the digital models started by scanning dental stone models using Ortho Insight 3D Desktop Scanner (Motionview, Chattanooga, Tenn) *(Figure 1)*. The digitally created replicas were then saved in STL format.

Figure 1: Ortho Insight 3D Desktop scanner

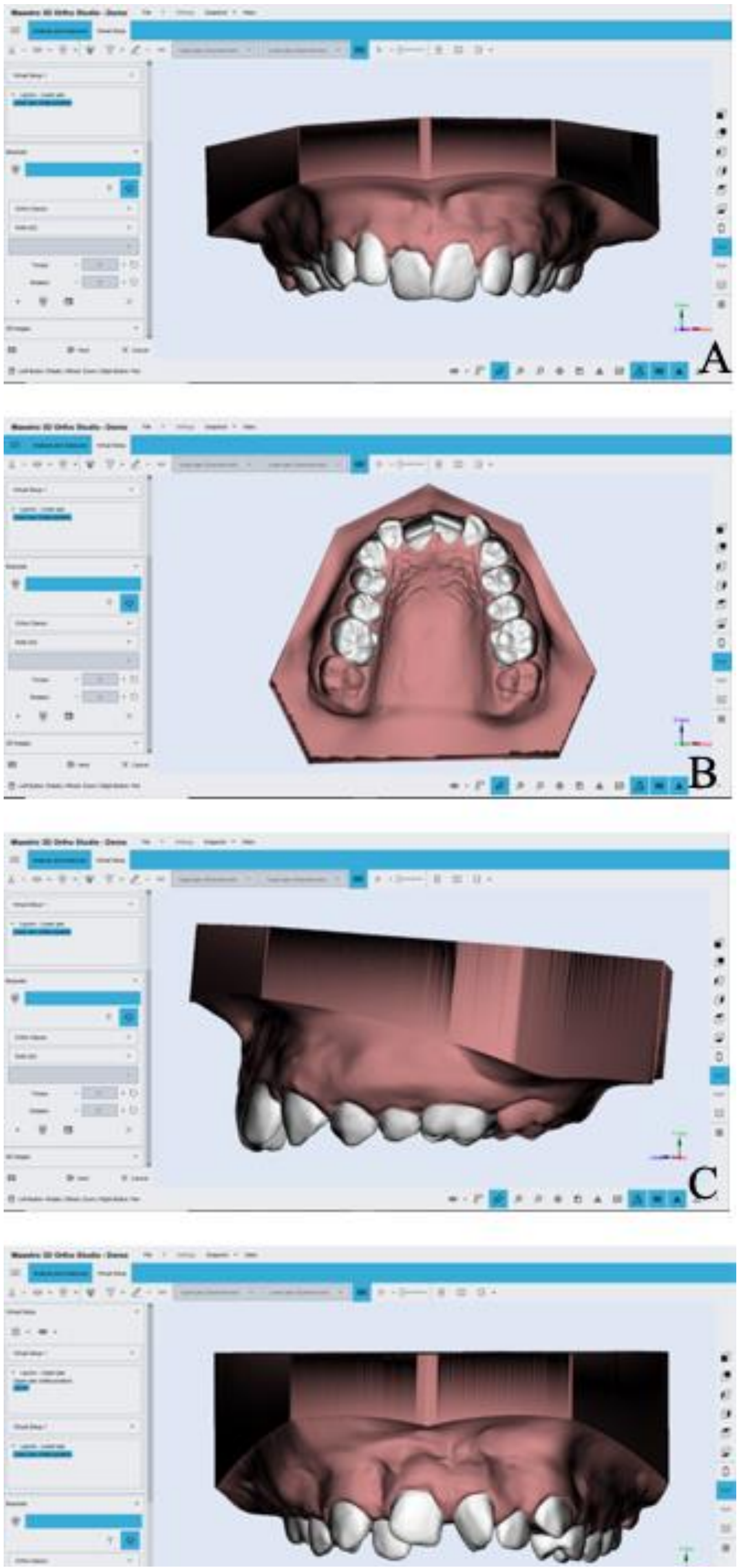


Figure 2:Digital model of moderate crowding in Maestro 3D Ortho Studio®(MS), A) Frontal view , B) Occlusal view , C) Right lateral view , D) Left lateral view

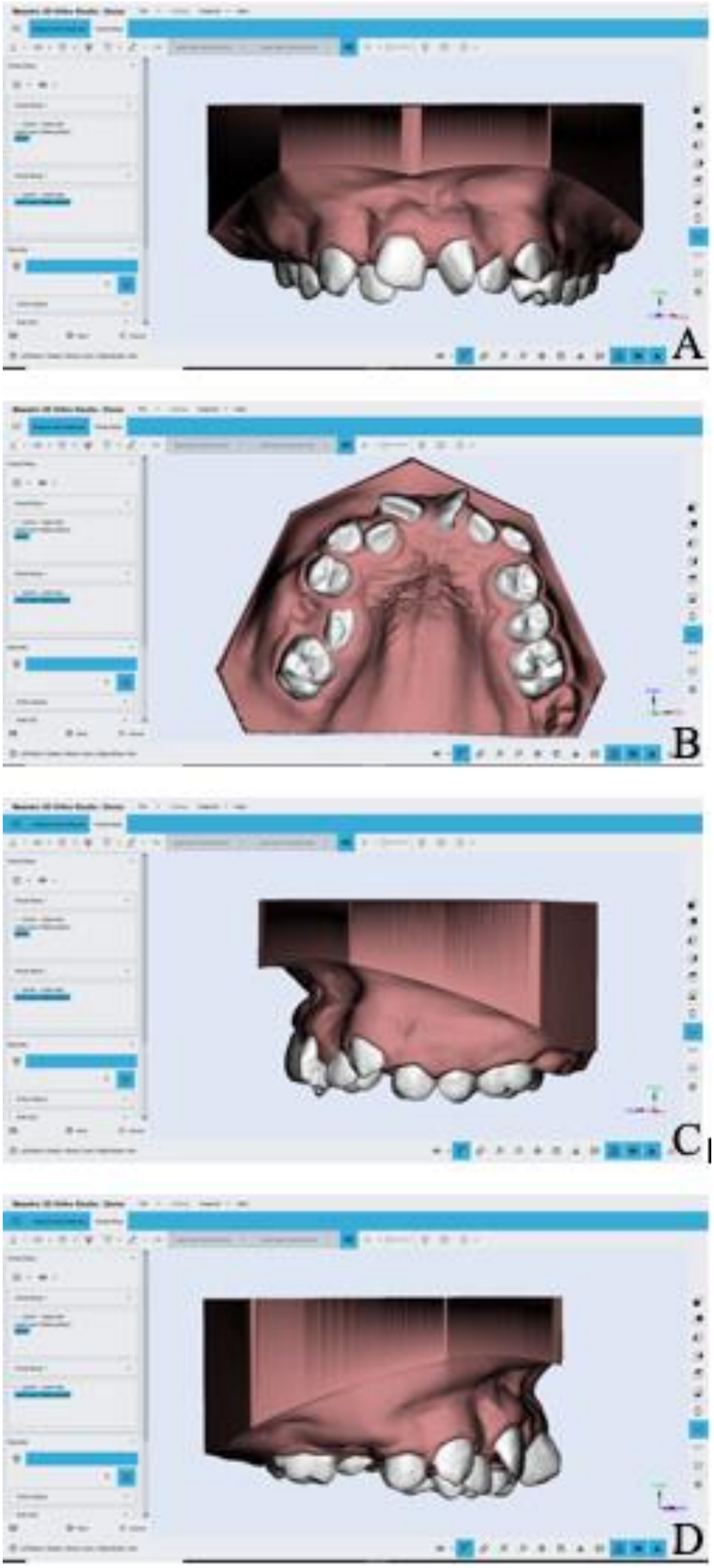
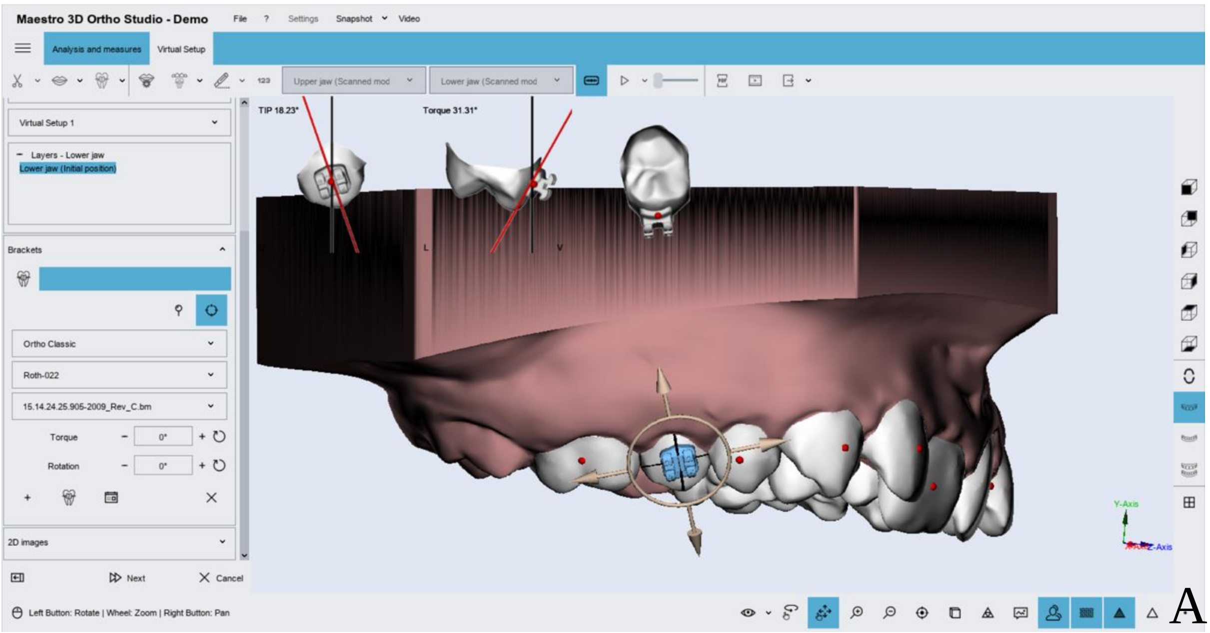


Figure 3:Digital model of severe crowding in Maestro 3D Ortho Studio®(MS), A) Frontal view, B) Occlusal view, C) Right lateral view, D) Left lateral view

4.2.Virtual Setup

4.2.1 Digital Bracket Placement

Stereolithography (STL) models generated previously were transported to Maestro 3D Ortho Studio® (MS) (AGE Solutions®, Pontedera, Italy) software *(Figure 2 and 3)* to perform the virtual brackets placement *(Figure 4)*. Ortho Classic Brackets (Roth 0.22', McMinnville, USA) used in this study were selected from the virtual bracket library available in Maestro 3D Ortho Studio software® and were digitally placed to the 3D models on the central incisors, laterals, canines and premolars *(Figure 5)*. Maestro 3D Ortho Studio® is a user-friendly software which allows for proper bracket positioning and fine adjustments in the three planes of space considering the height, angulation and mesiodistal tip of each bracket *(Figure 4)*. The digital models after brackets placement were considered as the gold standard for comparing the accuracy of brackets position.



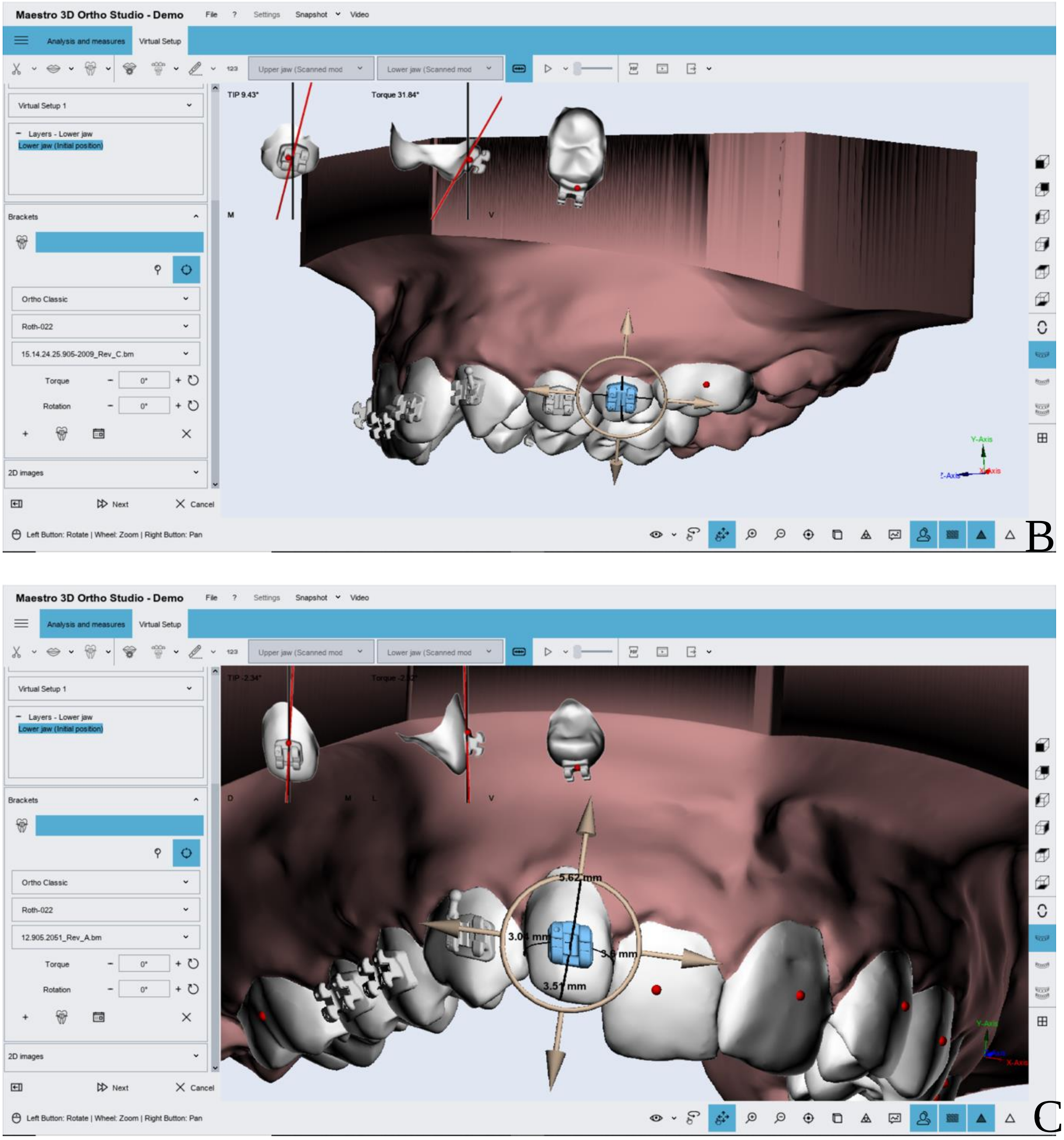


Figure 4: (A, B and C): Digital Bracket Placement using Maestro 3D Ortho Studio® (MS)

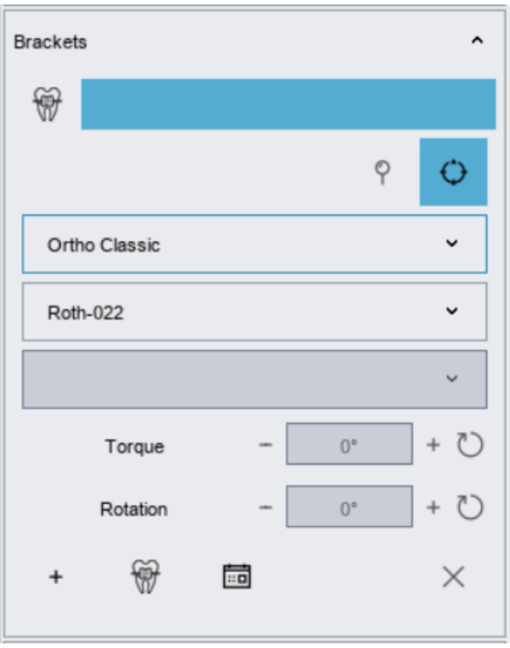


Figure 5:Bracket library

4.2.2 Designing the brackets transfer trays (One piece and Segmented)

Maestro 3D Ortho Studio® software was used for designing the digital transfer trays. The following rules were followed for creating both a one-piece transfer tray and a segmented transfer tray: 1) The virtual trays thickness were set to be 0.5 mm, 2) All trays were designed to cover the buccal cusps of the posterior teeth and incisal edges of the anterior teeth and then extended vertically just below the gingival margins from the labial and buccal aspects of each tooth, 3) The lingual aspects of posterior and anterior teeth were not covered, *(Figure 6, 7 and 8).* For making segmented transfer trays, additional cuts at the contact areas between the lateral incisors and canines were virtually made on both sides using the 3D printer software (3D-Sprint; 3D Systems, NextDent B.V., Soesterberg, Netherlands) for creating three-piece transfer trays. *(Figure 9)*

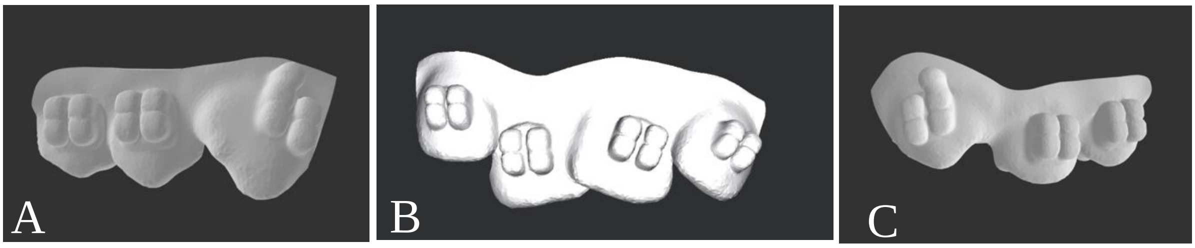


Figure 9:(A,B and C) : Segmented Transfer Tray design .A) right segment ,B) Anterior segment and C) left segment

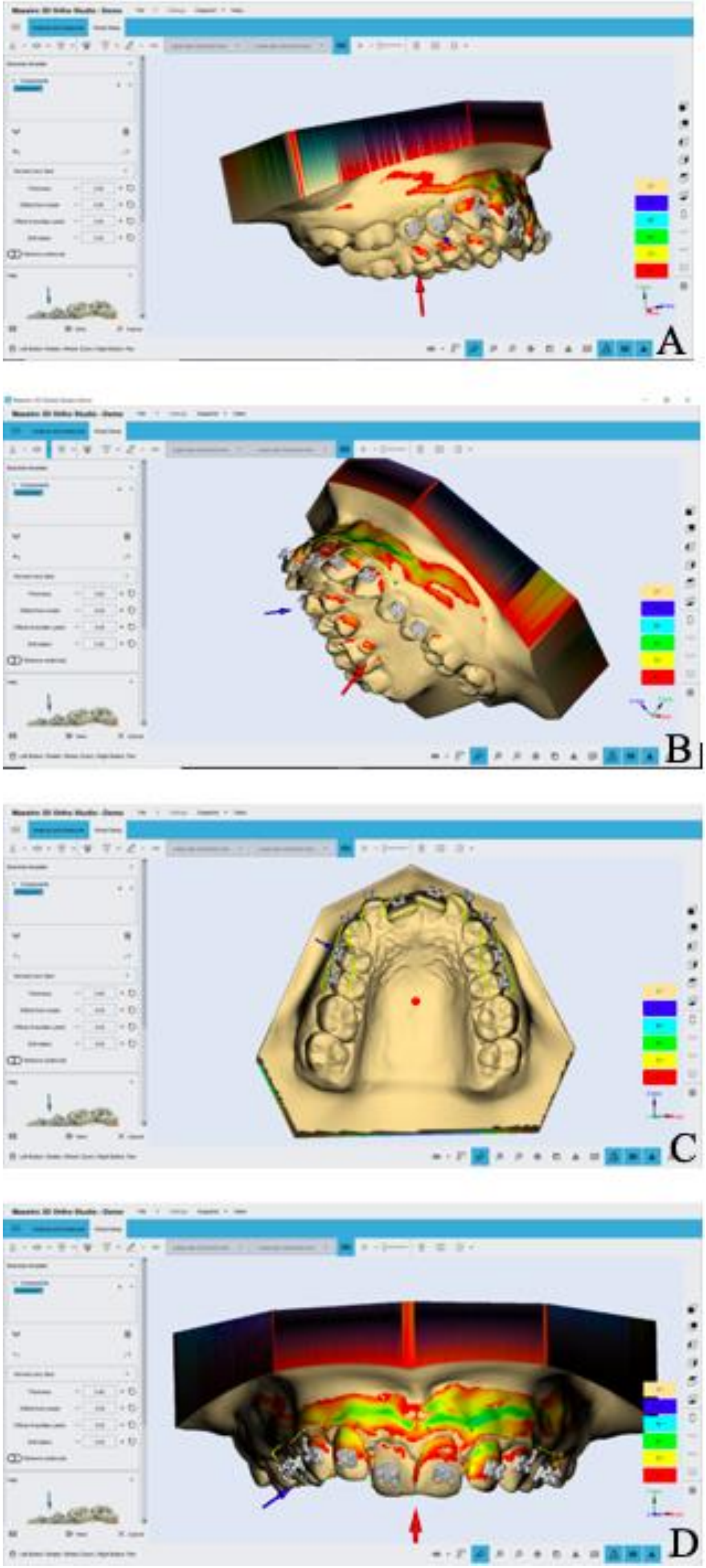


Figure 6: Transfer tray designing through Maestro 3D Ortho Studio® (MS) A and B) lateral views , C) Occlusal view and D) Frontal view

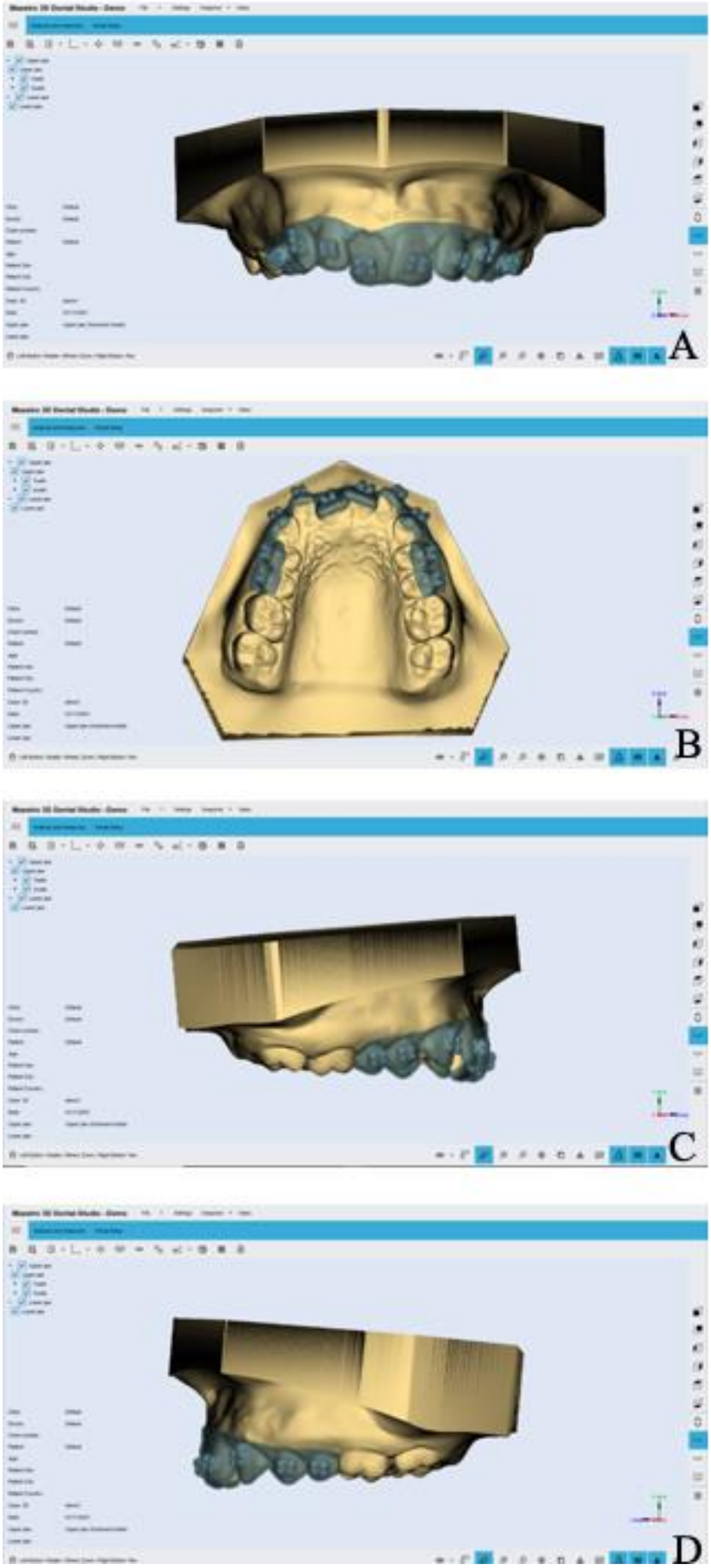


Figure 7:Full Piece Transfer Tray of the Moderate Digital model, A) Frontal view, B) Occlusal view, C and D) lateral views

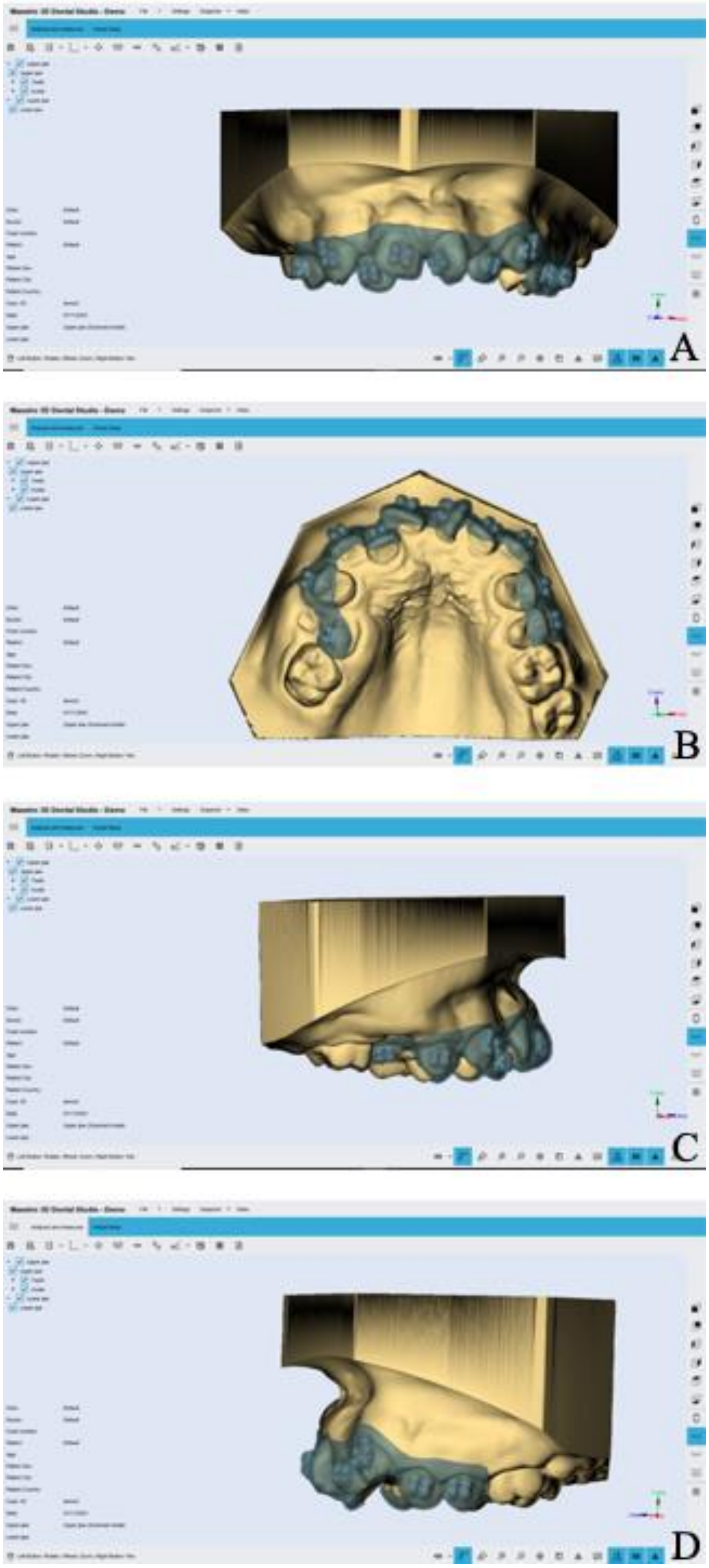


Figure 8:Full Piece Transfer Tray of the Severe Digital model, A) Frontal view, B) Occlusal view, C and D) lateral views

Figure 11:NextDent 5100 3D printer and the LC-3DPrinter Box

4.3.3D Printing

All STL files saved for digital models and brackets transfer trays were printed using the 3D printer (NextDent 5100; 3D Systems, NextDent B.V., Soesterberg, Netherlands) *(Figure 10).* Forty moderate, and 40 severe models were printed using light cured resin models material (NextDent Model 2.0) *(Figure 10).* The resin models were subsequently thoroughly cleaned from excess resin material using 99% alcohol rinse, before going through a final light cure using the LC-3DPrint Box *(Figure 11)* for a period of 10 seconds. Clear biocompatible printing material (NextDent Ortho Flex material) *(Figure 12)* used to print the brackets transfer trays. Because of the rigidity of the Ortho Flex material, all trays were cleaned and processed using the same steps but the curing step using light cure machine has been eliminated to preserve the tray's flexibility that is required to place and remove the trays over the physical models without causing any damage to the bonded brackets. In preparation for indirect bonding, brackets were manually inserted inside the transfer trays and each tray was then fitted over the printed models of the dentition to inspect for proper fitting *(Figure 13).*

Figure 10: Model 2.0 Material for the printing of the 3D models

Figure 12: Ortho Flex Material for the Indirect bonding transfer trays

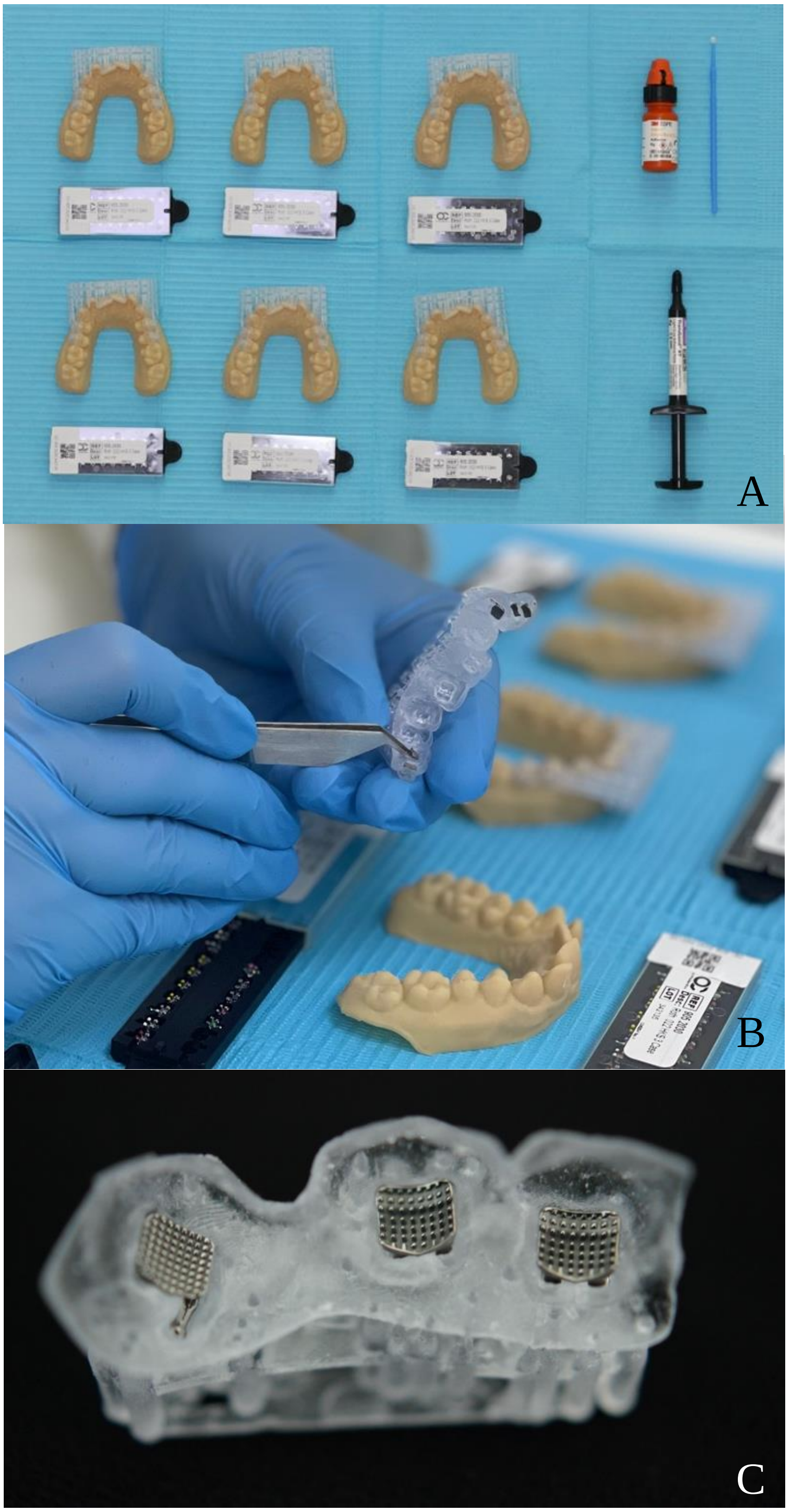


Figure 13 (A, B and C): Ortho Classic Brackets were placed manually into the trays and then fitted to the resin models to ensure proper fitting

4.4. Indirect Bonding Procedure

In all cases, only one operator performed the clinical bonding procedure who is well trained to perform the indirect bonding using this technique. Polishing and etching for the surface weren't required. A thin layer of Adper Single Bond 2 adhesive by 3M applied to the buccal surface and lightly cured *(Figure 14).* Then, a small amount of Transbond XT light-curing bracket adhesive (3M Unitek, Monrovia, CA) was applied to the base of the brackets *(Figure 15).* During placement, Trays were carefully positioned over the 3D printed resin models, the correct position was confirmed by visual inspection and seated using a light finger pressure on the occlusal surface *(Figure 16).* The adhesive resin then light-cured for 30 seconds per tooth in all directions *(Figure 17).* With the use of the plastic instrument, the trays were carefully removed and the excess adhesive was removed from around the bracket with a diamond round bur on a high-speed handpiece *(Figure 18 and 19)* The final resin model with the bonded brackets were carefully inspected *(Figure 20).* Six debonded brackets were recorded and excluded from the study.

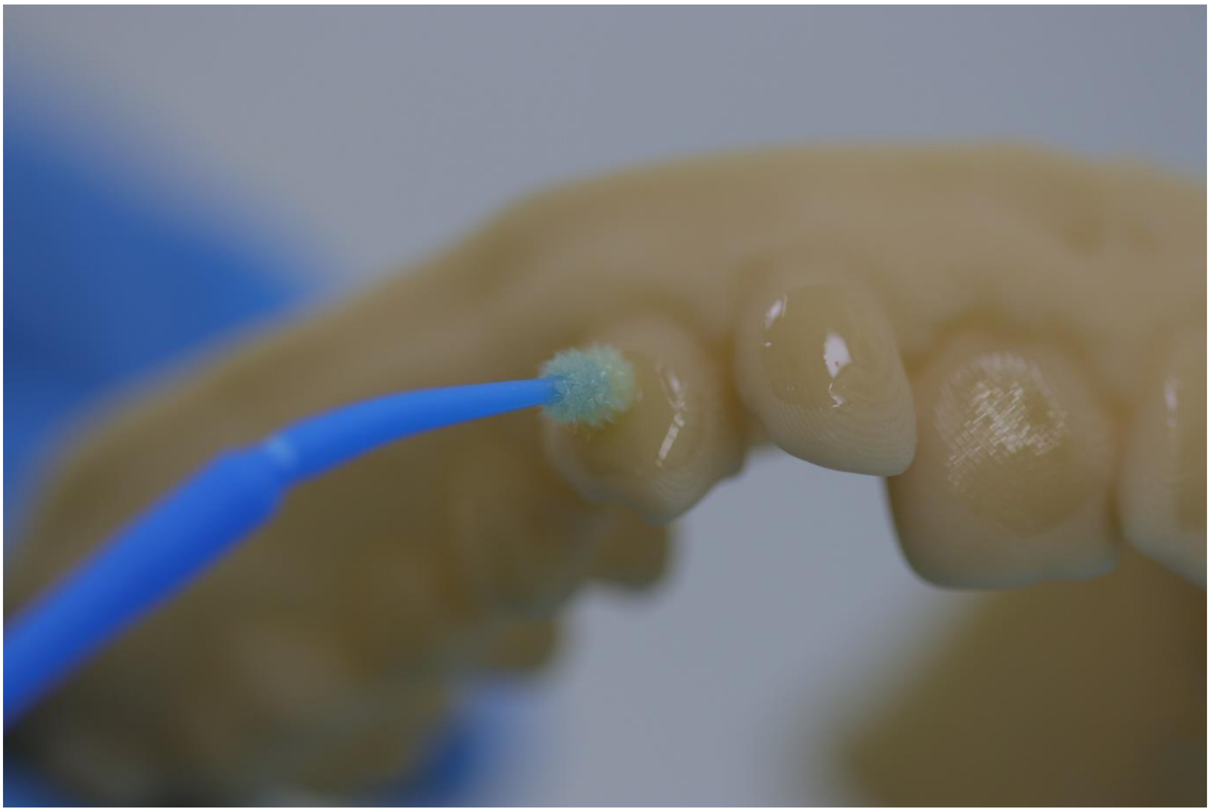


Figure 14: Applying a thin layer of Adper Single Bond 2 adhesive by 3M to the buccal surface and lightly cured

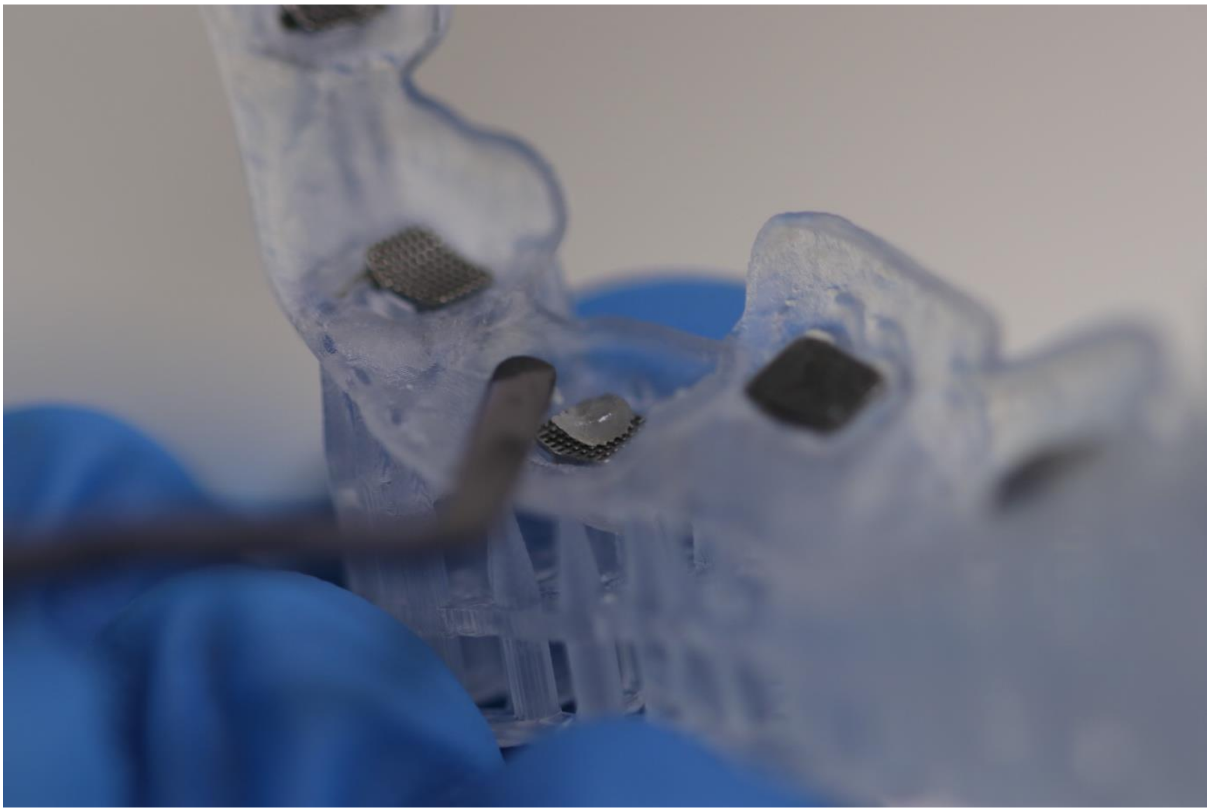


Figure 15: Transbond XT light-curing bracket adhesive was applied to the base of the brackets .

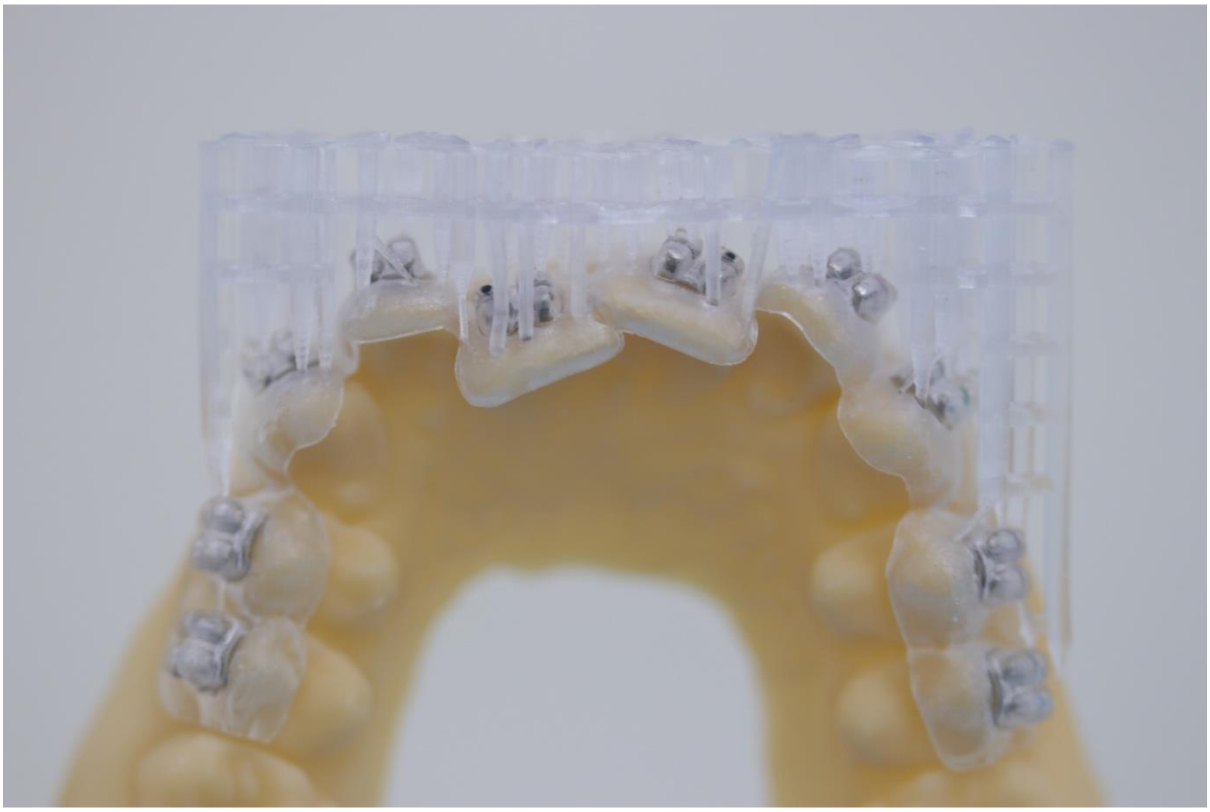


Figure 16: Trays was carefully positioned over the 3D printed resin models

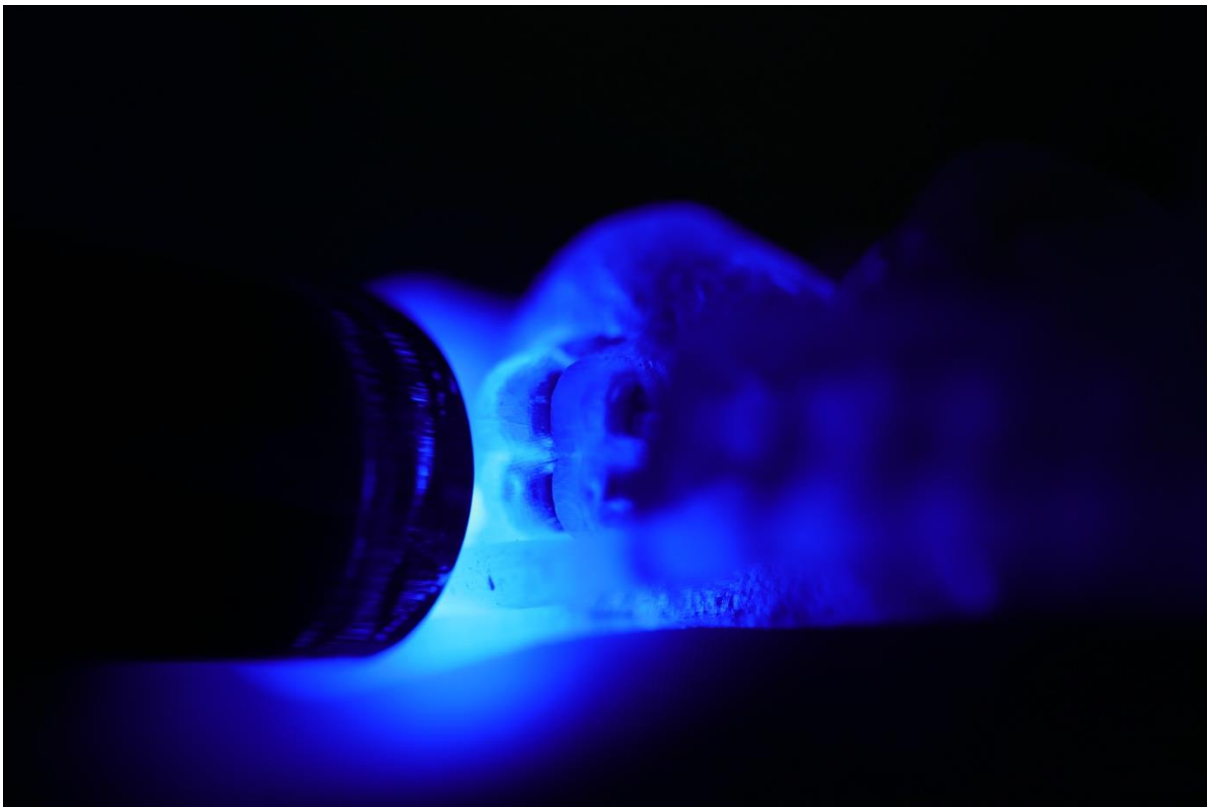


Figure 17: The adhesive then light-cured for 30 seconds per tooth in all directions.

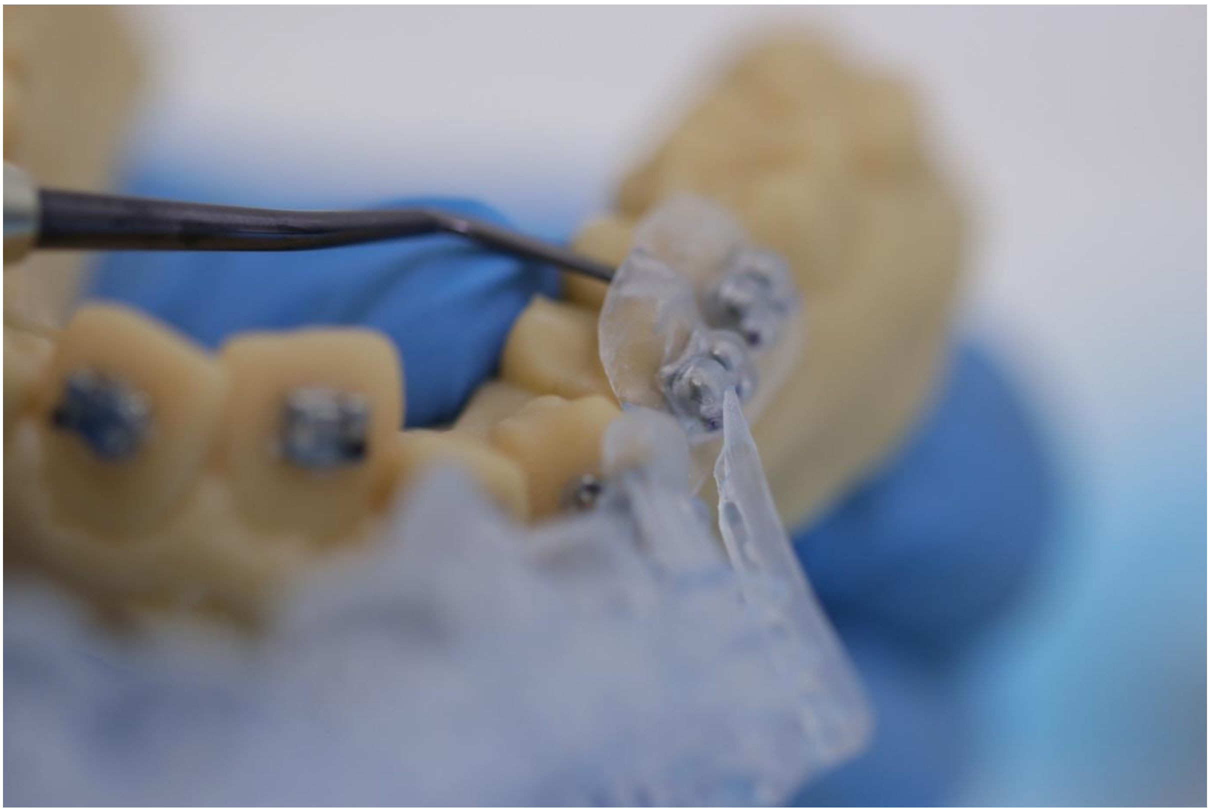


Figure 18: Plastic instrument used to facilitate the tray removal.

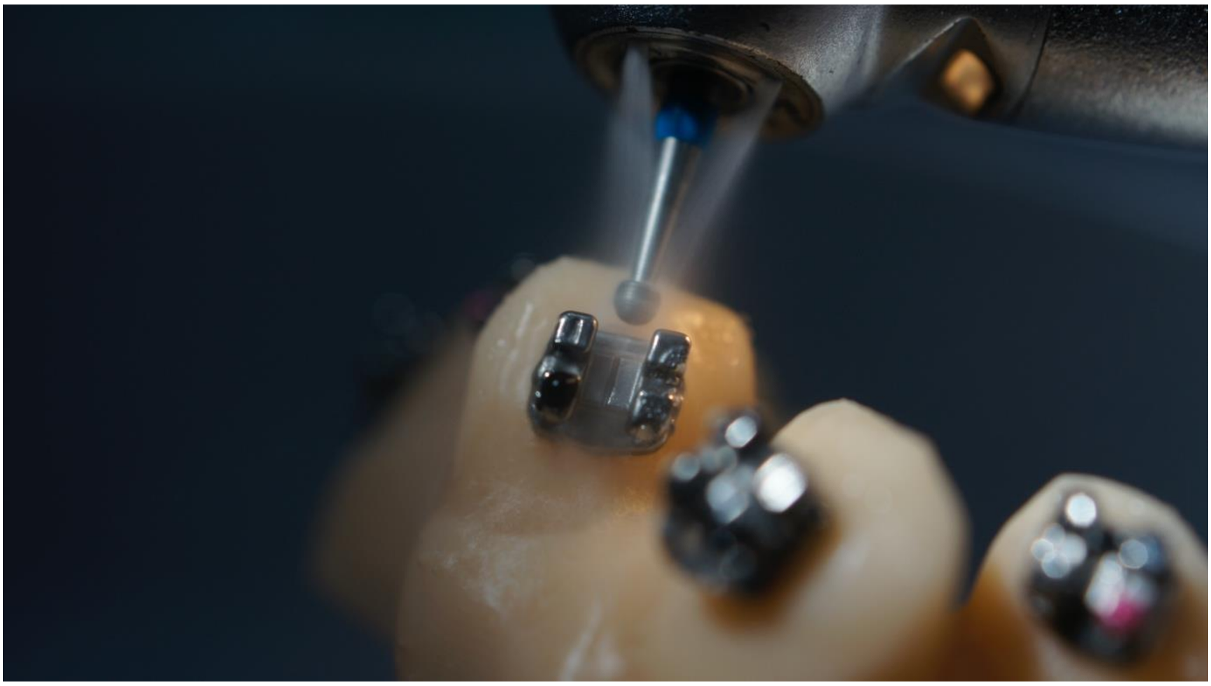


Figure 19: Excess adhesive was removed from around the bracket with a diamond round bur on a high-speed handpiece.

Figure 20: Final resin model with the bonded brackets

4.5. Scanning the Final Bonded Bracket Positions

Using the iTero Element scanner (Align Technology, San Jose, CA) *(Figure 22),* final scans of the models were taken after the brackets had been bonded to the teeth to visualize their final position *(Figure 22).* The resulting digital models, called (scanned printed models) were saved in STL format and transferred to Dolphin Imaging software (V 11.95 Dolphin Imaging and Management Solutions, Chatsworth, Calif.) for measuring the accuracy of the brackets position *(Figure 23).*

F*igure 21: iTero scanner used for intraoral scanning*

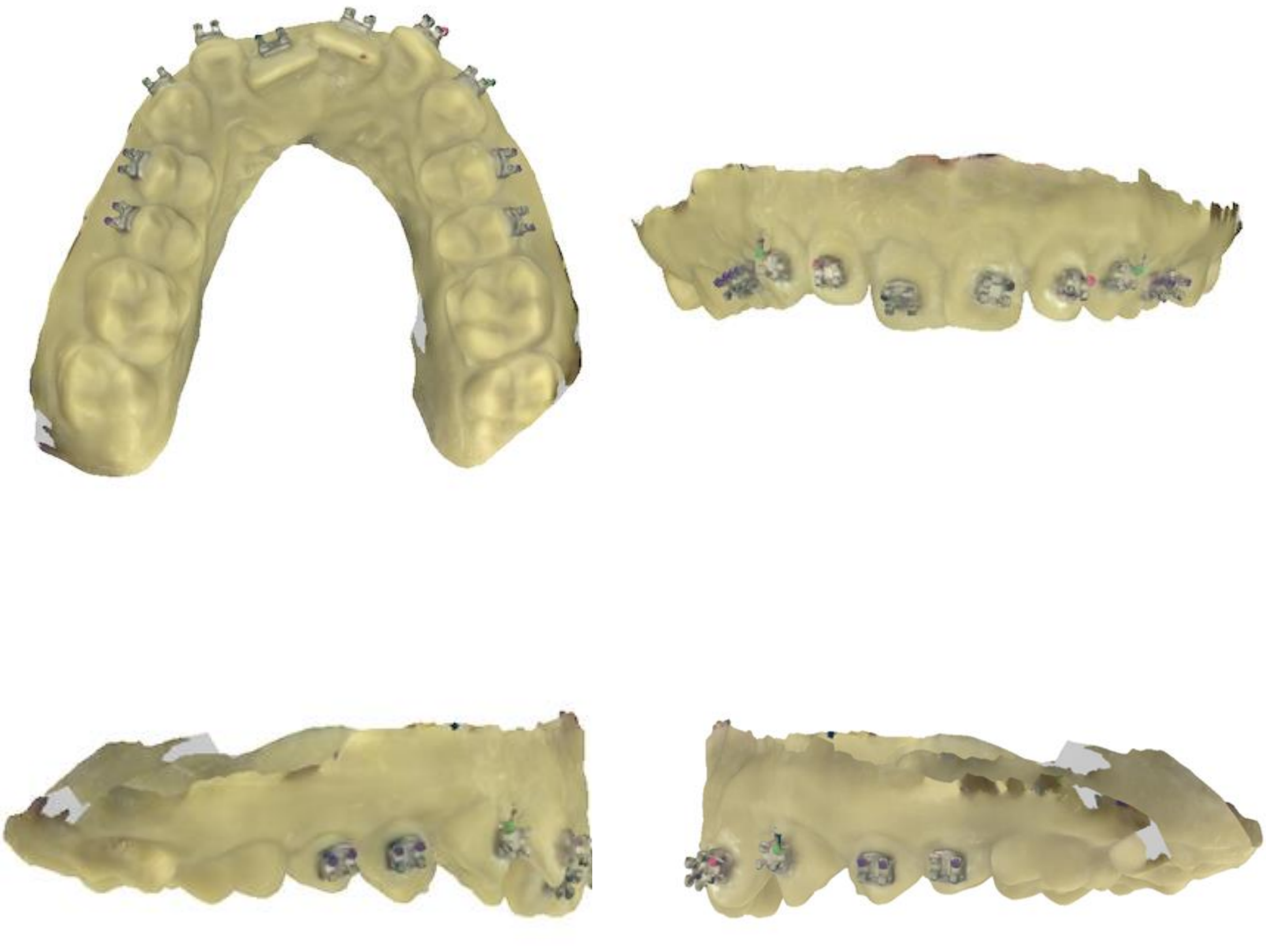


Figure 22: Final scan of the digital model with the brackets using the iTero scanner

4.6.Transfer Accuracy Measurements

Four points were selected in each tooth to perform the analysis. From the midpoint of each bracket to the mesial margin (CM= center mesial), distal margin (CD =center distal), occlusal/ incisal margin (CI= center Incisal/occlusal) and gingival margin (CG= center gingival) *(Figure 23)*. Ensuring that the line formed between the two points is parallel to the brackets' wing and perpendicular to its long axis.

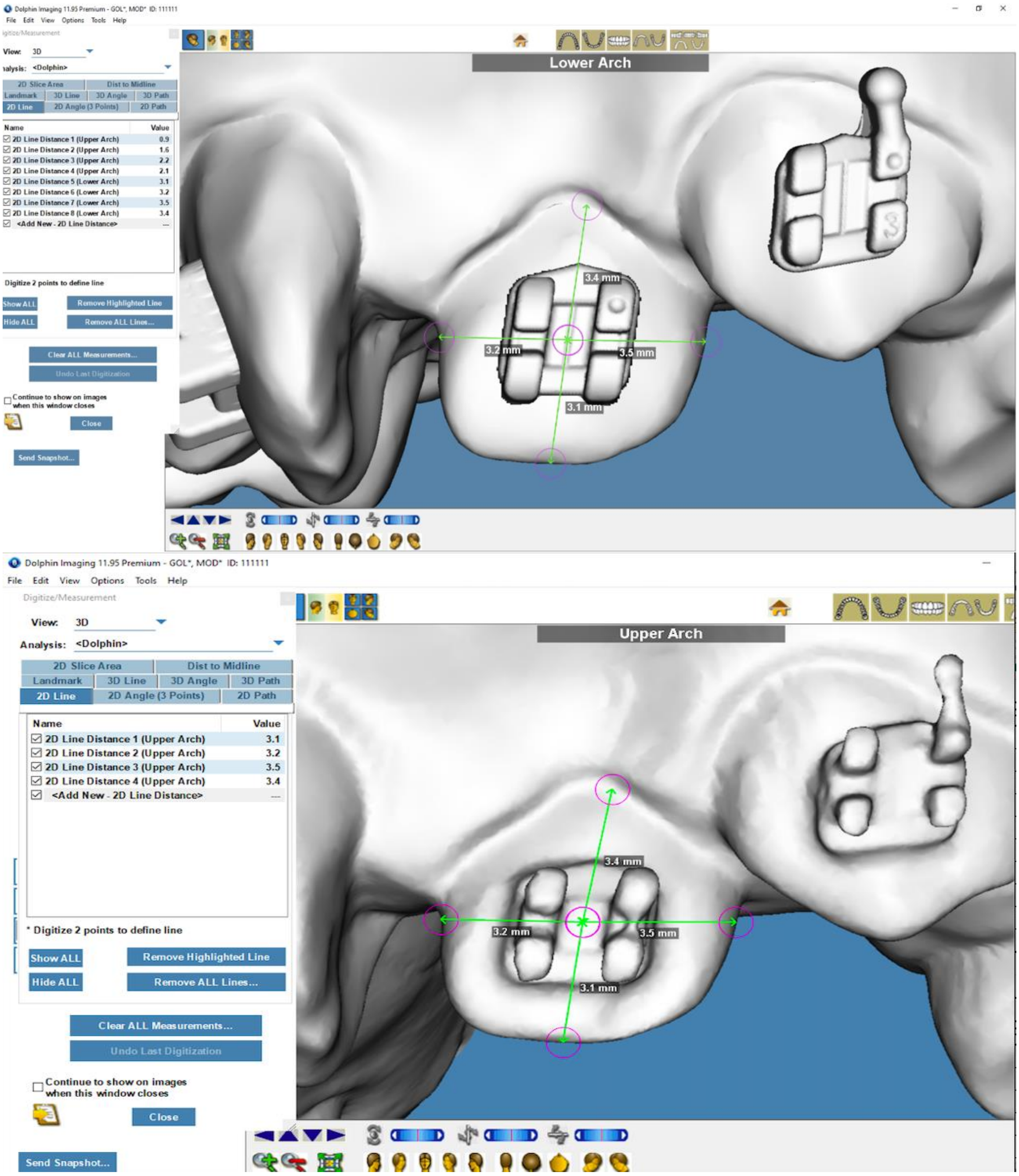


Figure 23: Dolphin Imaging software used to measure the transfer accuracy of the 3D-printed transfer tray according to 4 points CM, CD, CI and CG

4.7.Reliability

The reliability of brackets position was determined by repeating all measurements twice for 200 brackets using models with mild and severe crowding. The second round of measurements was performed by the same investigator after one-week interval period.

4.8. Statistical Analysis

Power calculation

$$\text{Power} = 1 - \beta = \varphi\ [(\mu_0 + z_\alpha \sigma]/(\sigma/\sqrt{n})$$

$$\varphi = z_\alpha + [\frac{(\mu_0 - \mu_1)}{\sigma}\sqrt{n}]$$

Where μ_0 *and* μ_1 are means in two groups, n is sample size and z_α is the quartile of 95%
Let take n = 20, $\mu_0 = 3.2$, $\mu_1 = 3.1, \sigma = 0.02$, and $z_\alpha = -1.645$ the calculation yields

$1 - \beta =$ = 1- φ (0.7255)= 93

Hence chance of find significant difference if it exists is 93%, means the power is enough to detect the expect difference.

Data was entered into the computer using IBM-SPSS for Windows version 28.0 (SPSS Inc., Chicago, IL). Shapiro-Wilk was used to test the normality of continuous variables. Data was described by means and standard deviations. The Mann-Whitney test was used to compare the means between two groups (moderate and severe). When comparing the means between more than two groups the Kruskal-Wallis H test was used. A P-value of less than 0.05 will be considered significant in all statistical analyses. Intraclass correlation coefficients (ICCs) along with 95% confidence intervals for the ICCs were calculated to assess the reliability.

5. RESULTS

5.1.Moderate full, Segmented

For the reliability test results, the ICCs within each group were greater than 0.90 for all measurements.

There were statistically significant differences between models with moderate crowding bonded using full, segmented transfer trays and control for CD12, CD21, CI25 ($p < 0.001$). While the rest of the measurements showed no significant differences between models bonded with moderate crowding using the full, segmented transfer trays, and control (p=1.0).

Non-significant differences were detected for CI15, CI12 (p = 0.130), CM14, CG12, CI11, CI21, CM21 (p= 0.374) and CD24, 0.229 for CI22, 0.384 CM22 (p = 0.394) as showing in *(Table 1).*

5.2.Severe full, Segmented

There were no statistically significant differences between models with severe crowding bonded using full, segmented transfer trays and control for CG15, CD15, CI14, CM14, CG13, CD13, CG12, CI12, CM12, CD12, CG11, CI11, CM11, CD11, CI21, CM21, CD21, CI22, CM22, CD22, CM23, CD23, CG24, CI24, CM24 and CG25 (p =1.0).

CD14, CG21, CG22, CG23, CD24 showed a p value of 0.374. CI25 showed a p value of 0.384. CI23 showed a p value of 0.145. CM13 showed a p value of 0.130while CI15, CM15, CG14, CI13 showed a p value of 0.1 as mentioned in *(Table 2).*

Table 1:Comparison of the consistency among moderate groups

		N	Mean (SD)	p-value
CG15	Moderate Full	20	2.6	1.0
	Moderate segmented	20	2.6	
	Control	20	2.6	
CI15	Moderate Full	20	3.7	0.130
	Moderate segmented	20	3.7	
	Control	20	3.71 (0.03)	
CM15	Moderate Full	20	2.6	1.0
	Moderate segmented	20	2.6	
	Control	20	2.6	
CD15	Moderate Full	20	3.8	1.0
	Moderate segmented	20	3.8	
	Control	20	3.8	
CG14	Moderate Full	20	3.3	1.0
	Moderate segmented	20	3.3	
	Control	20	3.3	

CI14	Moderate Full	20	4.1	1.0
	Moderate segmented	20	4.1	
	Control	20	4.1 (0.02)	
CM14	Moderate Full	20	3.3	0.374
	Moderate segmented	20	3.3	
	Control	20	3.3	
CD14	Moderate Full	20	3.7	1.0
	Moderate segmented	19	3.7	
	Control	20	3.7	
CG13	Moderate Full	20	3.7	1.0
	Moderate segmented	20	3.7	
	Control	20	3.7	
CI13	Moderate Full	20	5	1.0
	Moderate segmented	20	5	
	Control	20	5	
CM13	Moderate Full	20	3.2	1.0
	Moderate segmented	20	3.2	
	Control	20	3.2	
CD13	Moderate Full	20	5.1	1.0
	Moderate segmented	20	5.1	
	Control	20	5.1	
CG12	Moderate Full	20	6.1	0.374
	Moderate segmented	20	6.1	
	Control	20	6.1 (0.02)	
CI12	Moderate Full	20	4	0.130
	Moderate segmented	20	4	
	Control	20	4 (0.03)	
CM12	Moderate Full	20	3.2	1.0
	Moderate segmented	20	3.2	
	Control	20	3.2	
CD12	Moderate Full	20	3.4	<0.001*
	Moderate segmented	20	3.4	
	Control	20	3.5	
CG11	Moderate Full	20	5.4	1.0
	Moderate segmented	20	5.4	
	Control	20	5.4	
CI11	Moderate Full	20	4.5	0.374
	Moderate segmented	20	4.5	
	Control	20	4.5 (0.02)	
CM11	Moderate Full	20	4.2 (0.02)	1.0
	Moderate segmented	20	4.2	
	Control	20	4.2	
CD11	Moderate Full	20	3.7	1.0
	Moderate segmented	20	3.7	
	Control	20	3.7	
CG21	Moderate Full	20	6.5	1.0
	Moderate segmented	20	6.5	
	Control	20	6.5	
CI21	Moderate Full	20	4.6	0.374
	Moderate segmented	20	4.6	
	Control	20	4.6 (0.02)	
CM21	Moderate Full	20	4.4 (0.02)	0.374
	Moderate segmented	20	4.4	
	Control	20	4.4	
CD21	Moderate Full	20	4.1	<0.001*
	Moderate segmented	20	4.1	
	Control	20	4	
CG22	Moderate Full	19	5.4	1.0
	Moderate segmented	20	5.4	
	Control	20	5.4	
CI22	Moderate Full	19	4.4 (0.02)	0.229
	Moderate segmented	20	4.4	
	Control	20	4.4 (0.02)	
CM22	Moderate Full	19	3.3 (0.02)	0.384
	Moderate segmented	20	3.3	
	Control	20	3.3 (0.02)	

CD22	Moderate Full	19	3.6	1.0
	Moderate segmented	20	3.6	
	Control	20	3.6 (0.02)	
CG23	Moderate Full	20	3.1	1.0
	Moderate segmented	20	3.1	
	Control	20	3.1	
CI23	Moderate Full	20	5.3	1.0
	Moderate segmented	20	5.3	
	Control	20	5.3	
CM23	Moderate Full	20	3.6	1.0
	Moderate segmented	20	3.6	
	Control	20	3.6	
CD23	Moderate Full	20	4.3	1.0
	Moderate segmented	20	4.3	
	Control	20	4.3	
CG24	Moderate Full	19	3.3	1.0
	Moderate segmented	19	3.3	
	Control	20	3.3	
CI24	Moderate Full	19	3.8	1.0
	Moderate segmented	19	3.8	
	Control	20	3.8	
CM24	Moderate Full	19	3.7	1.0
	Moderate segmented	19	3.7	
	Control	20	3.7	
CD24	Moderate Full	19	4	0.394
	Moderate segmented	19	4	
	Control	20	4.0 (0.02)	
CG25	Moderate Full	20	2.5	0.1
	Moderate segmented	20	2.5	
	Control	20	2.5	
CI25	Moderate Full	20	3.3	<0.001*
	Moderate segmented	20	3.3	
	Control	20	3.2 (0.02)	

Table 2:Comparison of the consistency among severe groups

		N	Mean (SD)	P-value
CG15	Severe full	20	3.5	1.0
	Severe segmented	19	3.5	
	severe control	20	3.5	
CI15	Severe full	20	2.1	0.1
	Severe segmented	19	2.1	
	severe control	20	2.1	
CM15	Severe full	20	4	0.1
	Severe segmented	19	4	
	severe control	20	4	
CD15	Severe full	20	2.5	1.0
	Severe segmented	19	2.5	
	severe control	20	2.5	
CG14	Severe full	20	2.6	0.1
	Severe segmented	20	2.6	
	severe control	20	2.6	
CI14	Severe full	20	3.9	1.0
	Severe segmented	20	3.9	
	severe control	20	3.9	
CM14	Severe full	20	4	1.0
	Severe segmented	20	4	
	severe control	20	4	
CD14	Severe full	20	3.7	0.374
	Severe segmented	20	3.7	
	severe control	20	3.7 (0.02)	
CG13	Severe full	20	3.5	1.0
	Severe segmented	20	3.5	
	severe control	20	3.5	

CI13	Severe full	20	4.5	0.1
	Severe segmented	20	4.5	
	severe control	20	4.5	
CM13	Severe full	20	3.6	0.130
	Severe segmented	20	3.6	
	severe control	20	6.8 (10)	
CD13	Severe full	20	4.1	1.0
	Severe segmented	20	4.1	
	severe control	20	4.1	
CG12	Severe full	20	3.4	1.0
	Severe segmented	20	3.4	
	severe control	20	3.4	
CI12	Severe full	20	3.4	1.0
	Severe segmented	20	3.4	
	severe control	20	3.4	
CM12	Severe full	20	3.5	1.0
	Severe segmented	20	3.5	
	severe control	20	3.5	
CD12	Severe full	20	3.5	1.0
	Severe segmented	20	3.5	
	severe control	20	3.5	
CG11	Severe full	20	4.6	1.0
	Severe segmented	20	4.6	
	severe control	20	4.6	
CI11	Severe full	20	4.4	1.0
	Severe segmented	20	4.4	
	severe control	20	4.4	
CM11	Severe full	20	4.5	1.0
	Severe segmented	20	4.5	
	severe control	20	4.5	
CD11	Severe full	20	4.5	1.0
	Severe segmented	20	4.5	
	severe control	20	4.5	
CG21	Severe full	19	3.4	0.374
	Severe segmented	20	3.4	
	severe control	20	3.4 (0.03)	
CI21	Severe full	19	4.7	1.0
	Severe segmented	20	4.7	
	severe control	20	4.7	
CM21	Severe full	19	4.2	1.0
	Severe segmented	20	4.2	
	severe control	20	4.2	
CD21	Severe full	19	4.5	1.0
	Severe segmented	20	4.5	
	severe control	20	4.5	
CG22	Severe full	20	3.4	0.374
	Severe segmented	20	3.4	
	severe control	20	3.4 (0.02)	
CI22	Severe full	20	3.1	1.0
	Severe segmented	20	3.1	
	severe control	20	3.1	
CM22	Severe full	20	3.2	1.0
	Severe segmented	20	3.2	
	severe control	20	3.2	
CD22	Severe full	20	3.5	1.0
	Severe segmented	20	3.5	
	severe control	20	3.5	
CG23	Severe full	20	3	0.374
	Severe segmented	20	3	
	severe control	20	3 (0.02)	
CI23	Severe full	20	3.8	0.145
	Severe segmented	20	3.8	
	severe control	20	7.04 (10.3)	
CM23	Severe full	20	3.4	1.0
	Severe segmented	20	3.4	
	severe control	20	3.4	

CD23	Severe full	20	3.9	1.0
	Severe segmented	20	3.9	
	severe control	20	3.9	
CG24	Severe full	20	2.5	1.0
	Severe segmented	20	2.5	
	severe control	20	2.5	
CI24	Severe full	20	3.4	1.0
	Severe segmented	20	3.4	
	severe control	20	3.4	
CM24	Severe full	20	3.7	1.0
	Severe segmented	20	3.7	
	severe control	20	3.7	
CD24	Severe full	20	4	0.374
	Severe segmented	20	4	
	severe control	20	4 (0.02)	
CG25	Severe full	19	2.2	1.0
	Severe segmented	20	2.2	
	severe control	20	2.2	
CI25	Severe full	19	3.5	0.384
	Severe segmented	20	3.5	
	severe control	20	3.5 (0.02)	

6. DISCUSSION

As part of their efforts to improve the treatment outcomes of orthodontic patients, orthodontists are slowly transitioning from reactive, and standard treatments to individualized and digital treatment methods (58). The advancement of indirect bonding in orthodontics in the last decade has been greatly anticipated. This technology provides great benefits for the clinician since it reduces the amount of chair time, improves bracket placement accuracy, and enhances patient comfort. Compared to direct bonding, indirect bonding was reproducibly more accurate when it came to bracket positioning with less torque error and rotation error (59, 60). The indirect bonding process also reduces plaque buildup around the orthodontic brackets and decalcifies white spots (61). Despite the popularity of indirect bonding technique in orthodontic treatment, there are still some disadvantages. For example, extra expenses on materials, time-consuming as well as skill-sensitive laboratory procedures (20).

Indirect bonding utilizing digital technology provides all the benefits of traditional indirect bonding as well as faster processing, computer-assisted model analysis, accurate bracket placement, standardization, ease of fabrication, and fewer manufacturing steps (27, 31, 33). The present study compared the accuracy of indirect bonding techniques in moderate, and severe crowding cases using three-dimensional printed one-piece transfer tray and segmented trays. This study found that there are no significant differences in the transfer accuracy of the one-piece and segmented indirect bonding trays in the moderate and the severe malocclusion.

Previous studies (Aguirre et al.(43) and Balut et al.(62)) have assessed the accuracy of bracket placement by comparing direct bonding to indirect bonding techniques and indicated that bracket placement showed no statistically significant differences between both techniques. However, they did not consider the errors that could result from improper bracket placement in mesio-distal direction although clinically such errors can cause rotational irregularities.

Furthermore, previous investigators who evaluated the vertical and angular discrepancies in bracket positions in different malocclusion using 2D photographic methods. They found less vertical and more angular discrepancies in placement of orthodontic brackets.

Several *in vitro* studies with 3D-printed trays (30), 3D printed jigs (63), and traditional transfer trays (57) showed better linear transfer accuracy compared to angular transfer accuracy. Kim *et al.* compared the digital bracket positions after indirect bonding of five maxillary arch models with intended digital bracket positions. The differences were investigated using a digital indirect bonding system. Kim *et al*. found high transfer accuracy in the linear dimensions (93–100% within acceptable range), and low transfer accuracy in the angular dimensions (43–73% within acceptable range) using 3D-printed jigs *in vitro (63)* . Niu *et al*. attributed the high transfer accuracy in the linear dimensions to the relatively rigid printed tray material (30). Based on their findings, researchers attributed weak angular control of bracket positioning was due to inconsistencies in the amount of adhesive used and by the tray design which provided relief for hooks and undercuts, potentially resulting in angular error. This suggests that thicker or more rigid transfer trays can improve angular control. In return, this would likely result in patient discomfort as well as a potential for higher bond failure rates due to difficulties of removing the bracket transfer trays following curing the orthodontic brackets. Similarly to the present study, Chaudhary *et al*. found low magnitudes and rates of *in-vivo* transfer errors in the linear dimensions when using 3D-printed transfer trays (means ranging from 0.002–0.032 mm for MD, 0.046–0.078 mm for OG, and 0.000–0.016 mm for BL dimensions) (64).

Bracket debonding during indirect bonding technique has been reported and has been referred to the possibility of bonding failure, weak curing technique, and/or improper design/material of bracket transfer trays. Bond failures in this study were almost exclusively related to bracket embedment in the tray material despite a low bond failure rate which was similar to that in previous studies for 3D-printed indirect bonding trays.

Six debonded brackets were recorded and excluded from the study. Two from each group of the one-piece, and one from each group of the segmented which gives the rate of 2:1 (one-piece to segmented) due to the difficulty while removing the one-piece tray. This finding is almost similar to what mentioned in other literature regarding the bond failure *in vivo (12).* It is possible that trimming and reducing the thickness of the trays could lower bond failure rates, but might result in less accuracy due to less rigidity. As it has been found that the transfer tray should be flexible enough to not cause any damage or bonding failure to the brackets during removal. In our study we eliminated the additional curing time required after the 3D Printing in order to manufacture transfer trays that would be rigid enough to secure the brackets position during bonding and flexible enough to avoid any damage during removal of the trays.

After loading the printed transfer trays with orthodontic brackets, the housing of each bracket may contain negative spaces around the edges of the physical bracket and the borders of the tray which may allow the excess bonding material to flow into theses spaces. This makes it difficult to completely remove the excess material before light-curing and makes the process of removing the cured material more tedious. Future study comparing transfer accuracy of 3D-printed trays with different trim margins, rigidity and thickness is required.

When identifying the bracket landmarks for measuring the accuracy of the bracket position on the scanned models, it was noticed that the borders of the bracket base were not clear enough to be used as a landmark which may impact the linear dimension. Instead, the midpoint of the bracket base was considered accurate in this study to measure the distances from the tooth margins (CI, CG, CM, CD) to the midpoint of each bracket. During scanning with the iTero scanner, which operates on the theory of light emission, the metallic brackets can scatter light rays, causing apparent multiplanar surfaces on the digital post-bonding scans (65). A review of the commercially available intraoral scanners revealed that the iTero scanner used in this study had excellent precision and trueness (66).

It has been noticed that bracket positioning errors might add up when there is severe overlapping between the adjacent teeth. Brackets might get deviated in opposite directions because of the severe overlapping. In our study we did not notice any increase in inaccuracies in bracket positioning between the overlapped teeth.

The iTero scanned typodont brackets in-vitro showed that the shape of the entire bracket slot was reproducible; a comparison with other scanners showed the iTero produced the most clear boundaries and sharpest images (66). *In vivo*, however, the situation is much different because of moisture and accessibility. On the other hand, Kang et al. found good accuracy of the scans on surfaces greater than 0.5 mm away from brackets in an *in-vivo* study on scanner accuracy on bonded dentition. This supports the idea it is likely that distortion was present on the reflective bracket surfaces that will negatively affect the angular measurement but not the linear measurements.

Bracket position could be influenced by the variability in tray seating, adaptation, ease of removal and the support of the 3D-printed tray (Figure 24). In this study, prior to bonding, adhesive material was manually placed on the bracket base. Errors in bracket positioning could be a result of the non-standardized amount of adhesive material that was left to the operator decision. A way to overcome this factor is using the pre-coated brackets.

To avoid separation from the build platform during printing, different support structures are necessary for different angulations. *Arnold et al*. discovered that the arrangement of objects on the build platform of SLA printers has an effect on accuracy. They found that the best accurate models are created in the front of the platform (67). *Unlovskiy et al.* on the other hand. Discover that objects placed in the center of the build platform are more accurate than those placed on the edge (68). In our study, the transfer trays covered the whole build platform according to their size and available space. More studies required on how platform placement and orientation affects accuracy.

The 3D printing software provides a smart support feature to be designed and printed with the printed trays. The smart support structure act as a scaffold to support the isolated parts of the printed trays at the initial steps of the 3D printing process. The scaffold structure should be removed after the print is complete which may create distortion to the printed trays and possible tearing of some parts. Caution to be taken while removing the support of transfer trays or designing the support in way that does not create distortion to the printed trays.

This study did not include the molars in the indirect bonding as they present a challenge. Compared to anterior brackets, we have found that posterior brackets are more prone to bonding failure (69). A future study including the molars will be valuable.

Additional studies are required to further validate the effectiveness of indirect bonding in vivo between the two transfer trays as the result will be influenced with additional factors that could result in greater errors. Example of the clinical challenges in Patients are such as restricted mouth opening, patient compliant and muscle movement, moisture control and soft tissue interference. In our study there was no soft tissue, so the tray and brackets could not displace gingival tissue in order to reach the proper bracket placement.

Gathering more accurate and complete data will improve the ability to measure differences in the bracket positioning. Indirect bonding may become more appealing to practicing orthodontists as technology progress.

7. LIMITATIONS

- In Vitro study
- 3D printer smart support
- Extra expenses on materials
- Skill-sensitive laboratory procedures

8. CONCLUSIONS

- The one-piece and the segmented indirect 3D printed transfer trays are accurate in the severe and moderate malocclusion.
- The severity of crowding doesn’t affect the accuracy of indirect bonding.
- Although the number of debonded brackets were higher using one-piece tray than the segmented tray, no statistically significant differences were found in the number of the desponded brackets among the different groups.

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