



Original Article

Comparative Study between the Overall Production Time of Digitally Versus Conventionally Produced Indirect Orthodontic Bonding Trays

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Cite this article as: Plattner J, Othman A, Arnold J, Von see C. Comparative Study between the Overall Production Time Digitally Versus Conventionally Produced Indirect Orthodontic Bonding Trays. Turk J Orthod 2020; 33(4): 232-8.

Main points:

- The total production time of indirect bonding trays was significantly higher in digital indirect bonding tray technique (DIBT) than in laboratory indirect bonding tray technique (LIBT).
- Although the total working and non-working time for DIBTs was longer, the active working time was significantly shorter, when compared to LIBT.
- The digital planning and production of 3D-printed indirect bracket transfer trays can be represented as a time-efficient production method.

ABSTRACT

Objective: The purpose of this study was to compare the production time for indirect digitally and laboratory-produced orthodontic bonding trays.

Methods: Orthodontic study casts were used in this study (n=40). The specimens were equally and randomly divided. In the digitally produced indirect bonding tray (DIBT) group (n=20), the brackets were set virtually using the Orthoanalyzer program (3Shape, Copenhagen, Denmark) to produce an indirect bonding tray that was virtually designed and 3D printed using VarseoWax® Splint material with a Varseo S 3D printer (Bego, Bremen, Germany). In the laboratory-produced indirect bonding tray (LIBT) group, the brackets were adhesively bonded to the study casts in the dental laboratory (Danube Private University, Krems, Austria), and a transfer bonding silicone tray was manufactured.

Results: The t-test results showed a significant difference between the passive time during the production of DIBTs (153.8±32.8 min) and LIBTs (7 min). However, the active production time was 13.6±0.8 min for DIBTs and 17.7±1.9 min for LIBTs. Every individual process step in both groups was measured in minutes, and statistical analysis was performed.

Conclusion: The total production time, including active working and passive non-working time, was higher for DIBTs than for LIBTs. However, the actual active production time for DIBTs was shorter than that for LIBTs. Within the study limitations, the digital planning and production of indirect orthodontic trays can be considered a time-efficient production method.

Keywords: 3D printing, bonding trays, digital orthodontics, indirect bonding, production time

INTRODUCTION

Patient demand for an esthetic smile has increased the need for orthodontic treatment. Minimizing the indirect bracket bonding duration is considered the main clinical challenge. In orthodontics, digital indirect bonding is considered a new era in daily practice.

Precise bracket placement is considered one of the main keys for successful orthodontic treatment, along with orthodontic diagnosis and treatment planning, which should fulfill the treatment goals (1). In indirect bonding,

the brackets are transferred clinically using a bonding tray (2). The indirect bonding technique can reduce the chairside time by 50%, according to several studies (3-5). Certain studies found that indirect positioning is more accurate and precise than direct bracket bonding because of accessibility, especially in the molar region (6, 7). The thin layer of orthodontic resin used in indirect bonding eliminates the excessive adhesive residues in addition to reducing plaque accumulation, caries risk, and white spot occurrence (8). The indirect bonding technique is preferred by patients and orthodontists (9). Since 1972, the instructions for indirect bonding tray (IBT) production have been published and were continually improved by numerous advancements in terms of materials (10, 11). Generally, IBTs are made of silicone-based polymers or thermoplastic materials (12, 13). The time taken for the indirect bonding technique is influenced by the method of manufacturing.

Digital indirect bonding using additive manufacturing technology offers a new alternative method to the plaster model of the patient's teeth. A special printable resin is used for 3-dimensional (3D) printing using the additive technique and is polymerized layer by layer (14).

The laboratory indirect bonding technique involves a dental technician stage in which the selected brackets are positioned and attached to the plaster model of the patient; silicone or thermoplastic materials can be used to fabricate the transfer trays, followed by clinical bonding of the bracket on the etched enamel using these transfer trays. The digital indirect bonding technique involves virtual positioning of the brackets using either a digitally scanned plaster model or a digital intraoral impression, followed by exporting the designed bonding transfer tray and printing it using a 3D printer.

Several studies evaluating the precision of indirect laboratory bracket positioning have been examined. In fact, IBTs using digital technology should be compared with conventional methods. Accordingly, the purpose of this experimental study is to compare and evaluate the production time needed to design and produce bonding trays using indirect laboratory-produced and virtually designed orthodontic custom trays. Both the active and the passive time used in both the techniques will be considered using *in vitro* analysis methods. This study aimed to compare the active working time required for bracket placement and the passive non-working time that serves as pause time or time spent in between tray production.

METHODS

A total of 40 adult study casts were included in this study. All of them were permanent dentition casts without morphological abnormalities.

All the study casts were duplicated using an additional silicone material (Adisil®, Goslar, Germany). The 40 study casts were divided into 2 equal groups: digital IBTs (DIBTs) and laboratory IBTs (LIBTs). In the DIBT group, the study casts were 3D scanned using the model scanner D800 (3Shape, Copenhagen, Denmark).

In both groups, the Discovery® smart brackets (Dentaurum, Ispringen, Germany) and Ortho-Cast M-Series buccal tubes (Dentaurum, Ispringen, Germany) were used. However, 3M Superior Fit Buccal Tubes MBT (3M Oral Care, Saint Paul, Minnesota, USA) were used for virtual bonding, whereas Ortho-Cast M-Series mini buccal tubes (Dentaurum, Ispringen, Germany) were bonded to the gypsum model in the LIBT group.

Laboratory Indirect Bonding Tray Technique

The clinical crown facial axis (FACC) and FA point were marked on each crown using a pencil (TL1: time spent for signing the FACC and FA point) (Figure 1). Then, the study cast was isolated with an isolating material (ISO-K, Wangen, Swiss) (TL2: time spent for isolating) and after 1 min of curing (TL3); every bracket was positioned on the FA point using a flowable light-cured resin (FlowTain™ L.V., Reliance Orthodontic Products Inc., Itasca, Illinois, USA) (TL4) (Figure 2). After checking the correct axis and mesiodistal relation, every bracket was polymerized for 12 seconds (TL5). The vestibular area of the study cast was blocked with wax strips (approximately 2–3 mm away from the bonded brackets) (TL6). Every bracket and the occlusal surfaces were embraced with transparent A-silicone (Memosil® 2, Heraeus Kulzer GmbH, Hanau, Germany) (TL7). After 5 minutes of curing (TL8), the tray was removed from the study cast and finalized with a scalpel (TL9) (Figures 3 and 4). Every procedural step (TL1–TL9) was measured in minutes. The overall production time was determined by TTL (Table 1).

Digital Indirect Bonding Tray Technique

Orthoanalyzer software (3Shape, Copenhagen, Denmark) was used for virtual bracket positioning. The teeth were segmented, and facial axis (FA) points were automatically calculated and manually modified for precise placement (Figure 5). The long axis of the teeth and mesiodistal relation were checked and adjusted (TD1), followed by automatic digital bracket bonding (TD2) (Figure 6). Thereafter, the virtually bonded study cast was converted

Table 1. Abbreviations used for different time measurements in both groups

TT	Total time of the entire production process (active and passive time) for laboratory (TTL) and digitally (TTD) produced trays
TtA	Total time spent for active process steps (active working time) for laboratory (TtLA) and digitally (TtDA) produced trays
TtP	Total time spent for passive process steps for laboratory (TtLP) and digitally (TtDP) produced trays
TBrA	Total time spent for active process steps during bracket bonding for laboratory (LTB) and digitally (DTB) produced trays
TTrA	Total time spent for active process steps during tray production for laboratory (LTT) and digitally (DTT) produced trays
TBrP	Total time spent for passive process steps during bracket bonding for laboratory (LTBP) and digitally (DTBP) produced trays
TTrP	Total time spent for passive process steps during tray production for laboratory (LTP) and digitally (DTP) produced trays

into a “bracket transfer master model” in which the undercuts on the brackets were blocked out, and an indirect transfer tray was designed (TD3). Before preparing the tray for printing via the nesting process using CAMbridge™ software (Bego, Bremen, Germany), another bonding tray was designed and then nested onto the same platform (TD4) (Figure 7). The last step (TD5) was 3D printing, which was manipulated using VarseoWax® Splint material with a Varseo S printer (BEGO, Bremen, Germany). Each print consisted of 2 IBTs that were post-processed for 10 minutes in an ethanol solution in a non-heated ultrasonic bath (TD6) (Figure 8). Later, the trays were polymerized for another 5 minutes in a light-polymerization unit (TD7) and separated from the printing supports (TD8). Every procedural step (TD1–TD8) was measured in minutes. The overall production time was determined as TTD (Table 1).

The total time spent for production was divided into active and passive steps. In the LIBT group, the active steps included manual bracket positioning on the study cast and production of the silicone transfer tray (TtLA=TL1 to TL7 and TL9). Passive production steps in the DIBT group consisted of printing 2 transfer trays on 1 platform and cleaning them in an ultrasonic bath, followed by light polymerization.

Statistical Analysis

Statistical analysis was performed with IBM SPSS Statistics 23 (IBM Corp.; Armonk, NY, USA). The nonparametric Mann–Whitney U test was used to compare the time spent for each step between both groups. The significance level of analysis was set at p<0.05.

RESULTS

The active steps, including manual bracket positioning on the study cast and silicone transfer tray production (TtLA=TL1 to TL7 and TL9), took significantly longer than the time required to po-

sition the brackets on the 3D study cast and design the transfer tray (TtDA=TD1+TD2+TD3+TD4+TD8) (Table 2) (p<0.01). Passive production steps in the DIBT group consisted of printing 2 transfer trays on 1 platform and cleaning them in an ultrasonic bath, followed by light polymerization. These steps (TtDP=TD5+TD6+TD7) took 2 hours and 33.08 min on average (Table 2).

In the DIBT group, the mean total time for 3D orthodontic tray production was 167.4±32.4 minutes, whereas the LIBT group

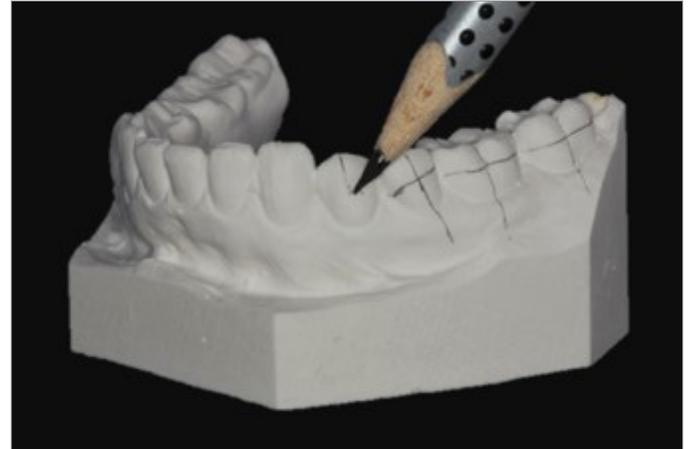


Figure 1. Marking the clinical crown facial axis and facial axis point



Figure 2. Placing the brackets



Figure 3. Fabrication of the silicone transfer tray

Table 2. Comparison of time spent for each step between DIBT and LIBT with Mann Whitney U test

Procedural step	DIBT Mean ± SD (n:20)	LIBT Mean ± SD (n:20)	p
TT(a)	167.4±32.4	24.7±1.9	0.001
TtA(b)	13.6±0.8	17.7±1.9	0.001
TtP(c)	153.8±32.8	7±0	0.001
TBrA(d)	1.8±0.25	12.4±1.4	0.001
TTrA(e)	11.8±0.78	5.2±0.75	0.001
TBrP(f)	0±0	1±0	0.001
TTrP(g)	153.8±32.8	6±0	0.001

(a) Total time of the entire digital production process (active working and passive non-working time)
 (b) Total digital/laboratory active working time
 (c) Total digital/laboratory passive working time
 (d) Total time spent for active process steps during digital/laboratory bracket bonding
 (e) Total time spent for active process steps during digital/laboratory tray production
 (f) Total time spent for passive process steps during digital/laboratory bracket bonding
 (g) Total time spent for passive process steps during digital/laboratory tray production



Figure 4. Finalizing the indirect bracket bonding tray

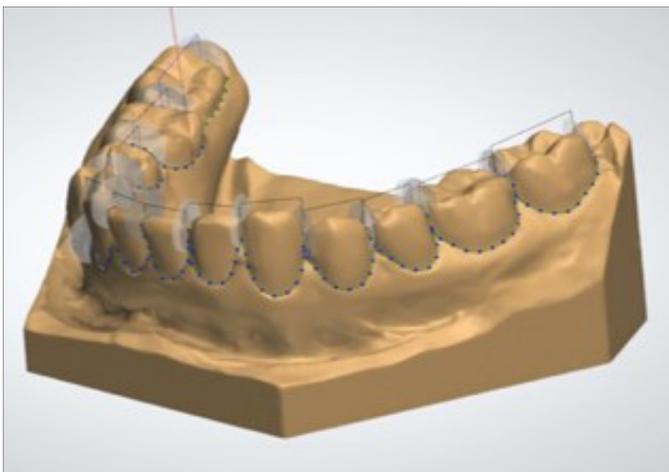


Figure 5. Segmenting tooth crowns

showed a significantly shorter total time for custom silicone tray production, with an average of 24.7 ± 1.9 minutes ($p=0.001$).

This study compared the passive production steps in both groups, which were significantly different ($p<0.01$). The LIBT group had less passive time than the DIBT group (Figure 9). LIBT processing took an average of 7 min ($TtLP=TL3+TL8$). $TtLP$ did not vary as specified by the manufacturer; thus, the standard deviation was 0 seconds. On the other hand, time spent on active process steps in the digital indirect bonding tray (DIBT) and laboratory indirect bonding tray groups showed a significantly shorter time for DIBT (Figure 10).

The total active time ($TtDA$, $TtLA$) was subdivided into a bonding process (DTB, LTB) and a production process (DTT, LTT) (Tables 2). Model segmentation and bracket positioning on the virtual study cast (DTB= $TD1+TD2$) took 1.8 ± 0.25 min on average, whereas marking the FA point, isolating the study cast, and manually positioning the brackets (LTB= $TL1+TL2+TL4+TL5$) took 12.4 ± 1.4 min on average. The time needed for LTB was significantly higher than that needed for DTB ($p<0.01$). In the DIBT group, DTT ($TD3+TD4+TD8$) was the nesting process during which 2 bonding trays were finalized by separating them from the printing supports. The steps of this process were significantly more time-consuming than those for conventional transfer tray production ($LTT=TL6+TL7+TL9$) ($p<0.01$).

Furthermore, the total passive production time ($TtDP$, $TtLP$) was subdivided into bonding (DTBP, LTBP) and transfer tray production (DTTP, LTTTP) segments. The passive time and the time needed for DTBP in the virtual positioning of the brackets was 0 seconds. Moreover, passive time during the manual bracket bonding was less than 1 min but still significantly longer than the time needed for DTBP ($p<0.01$).

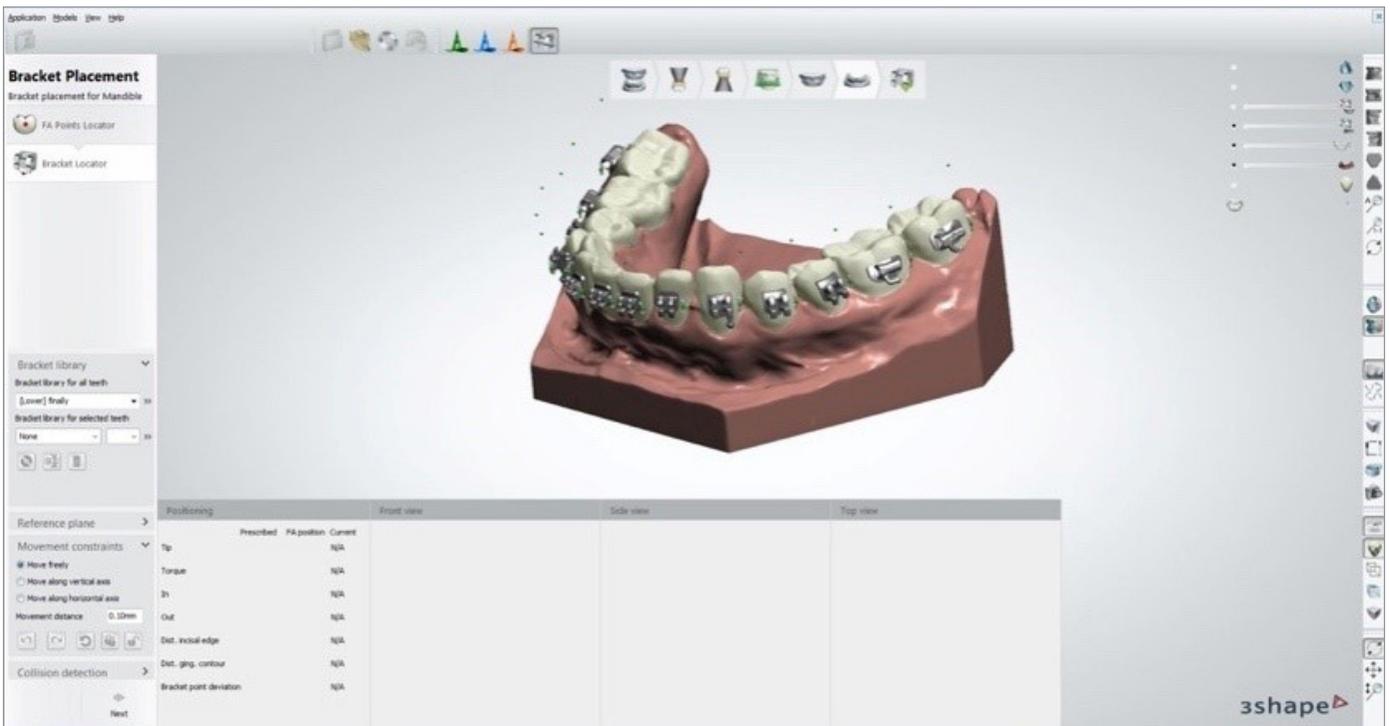


Figure 6. Automatically positioned brackets on the facial axis points

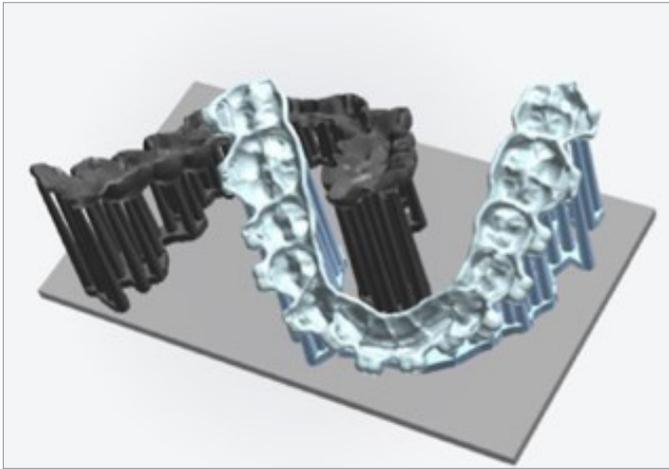


Figure 7. Nesting the transfer trays in CAMbridge™



Figure 8. Finalizing the 3D-printed indirect bracket bonding tray on the study cast

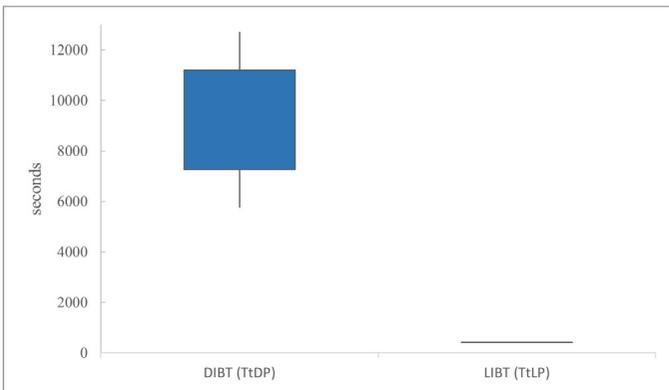


Figure 9. Comparison of the time spent on passive process steps in the digital indirect bonding tray and laboratory indirect bonding tray groups showing a significantly higher time needed in the DIBT group

DTTP corresponded to TtDP and showed a significantly longer total passive production time during digital transfer tray production than during silicone indirect custom tray (LTTP) production ($p < 0.01$) (Table 2).

DISCUSSION

This study aimed to compare the consumed time in indirect bonding systems using virtual planning (DIBT) and conventional (LIBT) methods.

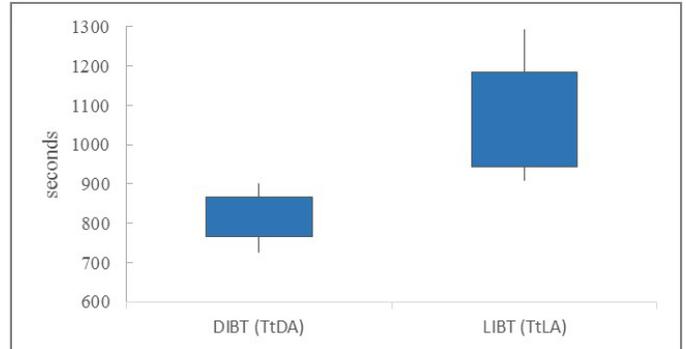


Figure 10. Comparison of the time spent on active process steps in the digital indirect bonding tray and laboratory indirect bonding tray groups showing a significantly shorter time needed in the DIBT group

For this purpose, a total of 20 study cast models were used per group. Intended bracket placement via CAD/CAM and conventional methods were compared, including the active working time and passive non-working time. Orthoanalyzer software was used for virtual bracket bonding, and a blinded experienced dental technician was asked to bond the study casts and fabricate the transfer trays. In both methods, time was calculated as working and non-working time zones. The total production time for LIBTs was significantly shorter than that for DIBTs. However, discrimination between active working and passive non-working steps should be differentiated. In LIBT processing, 9 steps (7 active, 2 passive) were needed, whereas DIBT processing needed only 8 steps (5 active and 3 passive). The virtual bracket bonding needed only 13.5% of the time needed for the plaster model. The digital production process takes only half as long as the laboratory processing.

The working time of the DIBT study group was found significantly shorter than that of the LIBT group. The non-working time for the DIBT group was found to be 91.8%, whereas that for the LIBT group was comparatively lower (28.2%). The duration mentioned in this study for the LIBT group was 24.74 min, which is considered lower than the results of the studies by Bozelli et al. (15) (26.24 min) and Aguirre et al. (16) (29.83 min).

In the LIBT group, production process took 6 hours and 12 min, whereas in the DIBT group, it took 23 hours and 6 min, of which only 3 hours and 30 min was the working time. The printing volume area of the 3D printer directly affects the amount of bonding trays per printed project. The Varseo S 3D printer with an overall volume of 96 mm×54 mm×85 mm (BEGO, Bremen, Germany) was used in this study for DIBT production. Align Technology (San Jose, California, USA) uses 3D Systems (Rockwell, South Carolina, USA) for Invisalign® 3D-printed models from the ProJet® 3510 MP printer, which has a construction volume of 298 mm×185 mm×203 mm, resulting in printing 24 models per print; however, the ClearCorrect (Round Rock, Texas, USA) uses the Objet30 OrthoDesk (Stratasys, Eden Prairie, Minnesota, USA), which has a build volume of 300 mm×200 mm×100 mm with a capacity of 20 models per print (17). The recommended computer requirements of 16 GB of RAM, 2 GB of GeForce, and 1 TB of free HDD storage for the appliance Designer™, Orthoanalyzer™, and CAMbridge™ programs were not met; instead, the computer

used in this study only met the minimum requirements. Accordingly, the duration of steps TD1, TD2, TD3, and TD4 could have been accelerated, thereby reducing the processing time.

The bracket positioning duration is also influenced by the operator; however, it was not taken into consideration in either manufacturing method because of high variance.

Careless handling while transporting the models can lead to undesired changes in the position of the brackets. With digital gluing, the program allows the orthodontist to monitor the position of the bracket on his/her own computer, regardless of the place of production. Israel et al. (18) examined the accuracy of digital bracket placement and compared with conventional bracket placement. They concluded that, there were no significant differences between the digitally positioned brackets and the manually glued brackets. This result allows us to assume that the DIBT and LIBT study groups might have an approximately equally accurate bracket placement. The assumption that an experienced orthodontist can place the brackets more precisely than a student has been researched by Armstrong et al. (19). and their results showed that there was no correlation between the accuracy of the bracket placement and the experience of the practitioner. The only difference was found for the time needed to bond the brackets, which was higher for the students.

In this study, a material (Memosil) was selected for the LIBT group, and silicone-produced trays were not separated into segments. Dörfer (20) demonstrated that, the selection of materials for aligner production with regard to the transmission accuracy showed significant results, and Memosil or Futar-D/Memosil should be preferred to 0.5 or 2-mm thermo-forming aligners and that the transfer trays should not be separated. The risk of bracket position movement was found to be the highest using thermoplastic aligners, unlike silicone, which can be carefully adapted to the brackets because thermoplastic material has no control over the pressure exerted on the brackets (21).

The VarseoWax® Splint material was used in the DIBT group, and there are still no studies regarding the transmission accuracy as an IBT. For an improved statement, further studies need to evaluate bracket bonding process on patients followed by an intraoral scan overlaid with a transfer plaster model. The brackets of laboratory-made transfer aligners have an individual adhesive base owing to the adhesive previously placed on the plaster model.

The adhesive base depends on the amount of adhesive used and the contact pressure of the brackets on the plaster teeth. Impairment of the adhesive bond of already polymerized adhesive bases has been frequently discussed in the literature; however, Aksakallı et al. (22) and Brandon et al. (23) reported an adhesive force that does not deviate from the directly glued brackets. This issue does not arise with the 3D-printed trays as a pre-settable adhesive strength (spacer) guarantees the uniformity of the adhesive, which is applied to the bracket base just prior to the gluing of the brackets.

CONCLUSION

The gross time of DIBT is indeed higher, but the net time compared to LIBT is significantly shorter. When considering the den-

tal technician working hours and thus the personnel costs for producing laboratory produced bracket transfer trays, the digital planning and production of 3D printed indirect bracket transfer trays can be represented as a time efficient production method.

Ethics Committee Approval: Ethic Committee approval is not necessary due to the nature of this study.

Informed Consent: Verbal informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Supervision – J.P., A.O., C.V.S.; Design – J.P., C.V.S.; Supervision – J.P., A.O., C.V.S.; Resources – J.P., C.V.S.; Materials – J.P., C.V.S.; Data Collection and/or Processing – J.P.; Analysis and/or Interpretation – J.P.; Literature Search – J.P., A.O., A.J.; Writing Manuscript – J.P., A.O., A.J., C.V.S.; Critical Review – J.P., A.O., C.V.S.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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