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ACCURACY ASSESSMENT OF BRACKET PLACEMENT BY INDIRECT BONDING TECHNIQUE USING THREE-DIMENSIONAL IMAGING AND STEROELITHOGRAPHIC PRINTING TECHNIQUE

[CLINICAL TRIAL]

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Abstract

Objective: this clinical trial was designed to assess the accuracy of bracket placement by indirect bonding by using three dimensional imaging and steroelithographic printing technique.

Materials and methods: a clinical trial was held on ten patients were planned to be bonded by full digital indirect bonding tray for upper arch. Intra- oral scanning of each patient was held after indirect bonding to get STL file for evaluation. Vertical brackets positions of total 120 brackets bonded were measured and evaluated. Intra class correlation and Bland Altman plot test were used to assess the accuracy of vertical bracket position of the full digital transfer tray.

Results: considering the whole units (120 units), excellent reliability and internal consistency (ICC>0.9) with p value < 0.001* with High level of agreement P value =0.089. For lateral incisors, canines and premolar groups, there was good reliability (0.9> ICC>0.75) with high level of agreement with p value = 0.068, 0.706 and 0.794 in order. An acceptable reliability (0.75>ICC>0.5) was found in central incisors and molars groups. The central incisors and molars groups exhibited a proportional bias in agreement test with by P value 0.047 *, 0.019* in order which is clinically insignificant. There was no statistical difference between the mean differences of the five groups P value = 0.185 .with range of mean differences (0.002:0.175) mm which was not clinical significant.

Conclusion: this protocol transferred the planed vertical brackets position from the virtual setup to the patient was generally highly accurate and reliable technique.

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Introduction

Placement of the brackets in an accurate manner is the most important aspect, after proper diagnosis and treatment. This helps treatment mechanics and improves the consistency of the results [1].

The only concern that made Angle and his students develop many systems of fixed orthodontic appliances in the modern era was precisely positioning of the root in each individual tooth. Thereafter, the contemporary edge wise appliance was developed.

Thought-out the ages, there are many trials for individualization the vertical brackets positioning: middle the clinical crown, gauge, and charts ….etc. All these methods for bracket positioning are dependent on the orthodontist's experience and his eye, without seeing the teeth roots of each individual tooth.

Andrew at 1980s developed bracket modification for specific teeth, to eliminate the many repetitive bends in arch wire that

were necessary to compensate for differences in crown anatomy [2].

From here straight wire appliance began. Every bracket has unique angulation and torque for more precise treatment.

Although, the direct bonding is considered as routine dental clinic nowadays, there is a major difficulty; the dentist must locate the accurate place of the bracket and place it rapidly and accurately. There is less opportunity for precise measurement of bracket position and adjustment with direct bonding than there would be in lab bench [2].

Indirect bonding techniques were introduced (1972) to reach required accuracy by Silvermann [3]. Conventional type of indirect bonding is done by placing the brackets on a mold in lab, then using tray or template to transfer the record to the oral cavity. However the evolution of indirect bonding technique, the individual inaccuracy in bracket placement can't be eliminated yet. The brackets used in this method needed to be cleaned for reattachment in oral cavity which may affect bond strength at micro level [4] or distorted from force of vacuum formed tray.

Recent imaging techniques have allowed complete visualization of the tissues in three dimensions, with the ability to produce accurate images of the patient's soft and hard tissue. Computer-aided manufacturing of dental stents derived from cone-beam images has a satisfactory degree of accuracy, allowing the implementation of Cone-beam computed tomography (CBCT) technology not only as a diagnostic tool but also as a treatment aid [5].

Therefore, accuracy assessment of bracket placement by indirect bonding by using CBCT and 3D printing guided by it, proved to be a point of worthy investigation. Accordingly this study we will be conducted to highlight this aim.

Patient and methods

The sample:

The sample included 10 patients (120 units) who were selected from the outpatient clinic of Department of Orthodontics, Faculty of Dentistry, Minia University.

A suitable sample size calculation was carried out to estimate the total unit with a good precision. The study design has a major impact on sample size calculation.

The following formula was used to calculate the required sample size;

$$N=\frac{(Z_{\alpha/2})^2\,S^2}{d^2}$$

Where N is the sample size, $Z_{\alpha/2}$ is normal deviate for two tailed alternative hypothesis at a level of significance, S standard deviation and d is margin of error. The level of confidence is 95% .

Ethical regulation:

- The study was approved by the Research Ethics committee of the Faculty of Dentistry, Minia University, Egypt.
- An informed consent was signed by the patient.
- A verbal approval was taken from the patient.
- All steps were explained to the patient.

Material and methods:

1. Digitalization the actual brackets:

After preparation of mold for brackets arrangement -with minimal distance between the brackets was 1 cm- a CBCT imaging was performed using Planmeca promax® 3D Mid CBCT Imagining unite by the following parameters: resolution (voxel size), HD (150µm); exposure time, 10sec; anode voltage, 90Kv; anode current, 10mA to get suitable DICOM file for brackets segmentation to get separate STL file for each bracket.

DICOM file was converted to STL file Using Materialized innovation suite v21.0 software. At 2000 HU as a minimal threshold point the mask was created and calculated to get surface sold STL file. This was saved separately for each bracket [fig 1]. The actual bracket used was American Orthodontics, Mini Master which was the available in the market.

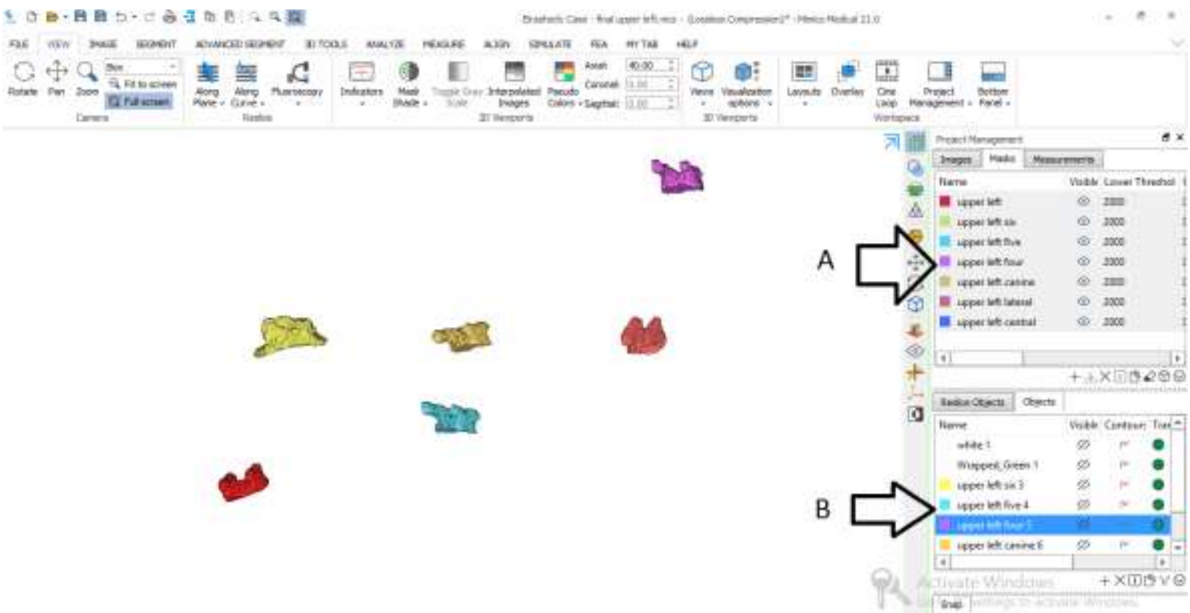

Fig1. Transformation process from DICOM to STL format. **A,** mask menu**. B,** object menu from which we create separate STL files.

2. Patient imaging:

A CBCT imaging was performed for each patient using the following parameters: resolution (voxel size), normal (200µm); exposure time, 12 sec; anode current, 6.3 mA; anode voltage, 90 kV using the same imaging machine previously mentioned.

The segmentation of each patient DICOM file was done file Using Materialized innovation suite v21.0 software to get a clear view of the teeth with their teeth.

The segmentation was began by macro subtract of large part by using edit mask tool in 3D view, while refinement as micro editing was done by edit mask tool in sagittal or axial view slice by slice.

Finally, calculate part was chosen from a side menu on the mask label to form solid 3D object, which enabled to save teeth with clear view of their roots as STL file [fig 2].

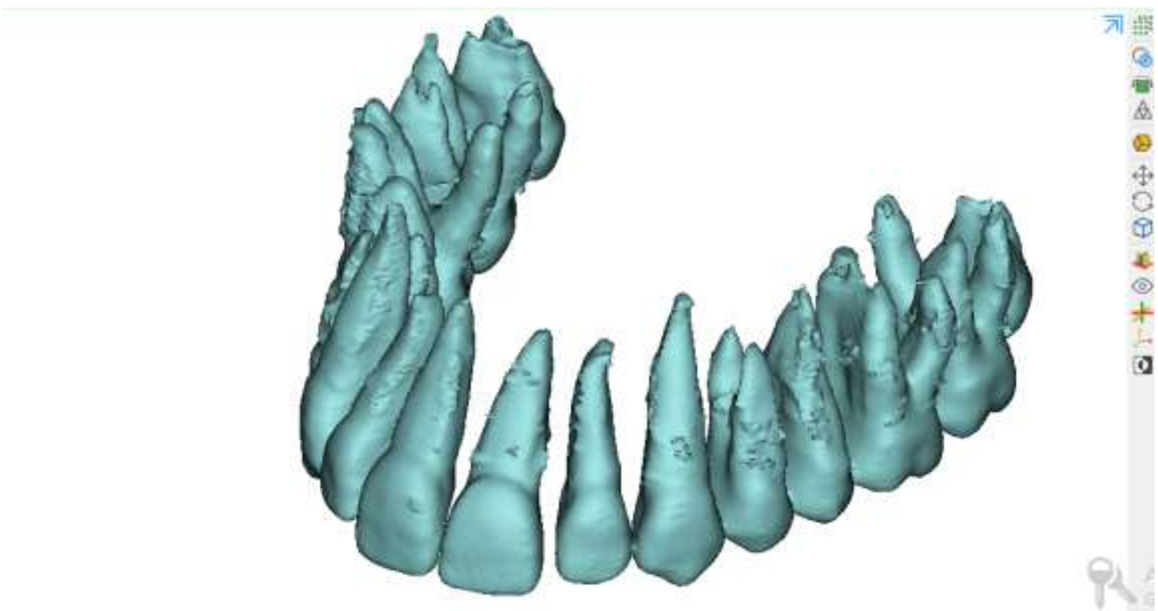

Fig2. Result of Segmentation of patient's teeth.

3. Virtual brackets positioning and tray designing

On Materialized 3- matic v11.0 software virtual bracket positioning on modified kalange method. The virtual positioning began by detecting marginal ridges of the posterior teeth mesial and distal. A point on each marginal ridge from the occlusal view of SLT of upper jaw of the patient was created. From buccal view the points detecting marginal ridge of each tooth was connected to create marginal ridge line. Above the marginal ridge line by 2 mm, slot line was created. At which the bracket was positioned vertically in posterior teeth. For anterior teeth, vertical positioning was calculated from first premolar vertical position plus 0.5 mm for canine and central incisor and the same length for lateral incisors [fig 3-4]. The vertical position height was measured from each tooth from occlusal or incisor edge to slot line and used as standard measuring to assess the transfer.

The tray designing was begun after complete brackets virtual positioning by drawing the outline of the tray on a new sketch. The tray creation was done by using the extrusion tool to get a sold surface of the tray with negative place for teeth and bracket seats [fig 5] which saved in STL file ready for 3D printing.

4. 3D printing of the tray

Using NextDent® 5100 3D printer the STL file of the tray was printed to get tray with indentation for bracket seating. After post curing and disinfection staged the actual brackets place into the tray and it was ready for indirect bonding [fig 6]. NextDent® 3D system resin model 2.0 was used as printing material biocompatible and CE certified in accordance with medical device directive 93/42/EEC, listed at FDA.

5. Indirect bonding process

After patient preparation by etching and bond application, adhesive material was applied to brackets [Fig 7]. The tray with bracket [Fig 8] was inserted into its position. Adhesive material excess was removed and finally curing 20 sec for each bracket was done. The tray was carefully removed [fig 9].

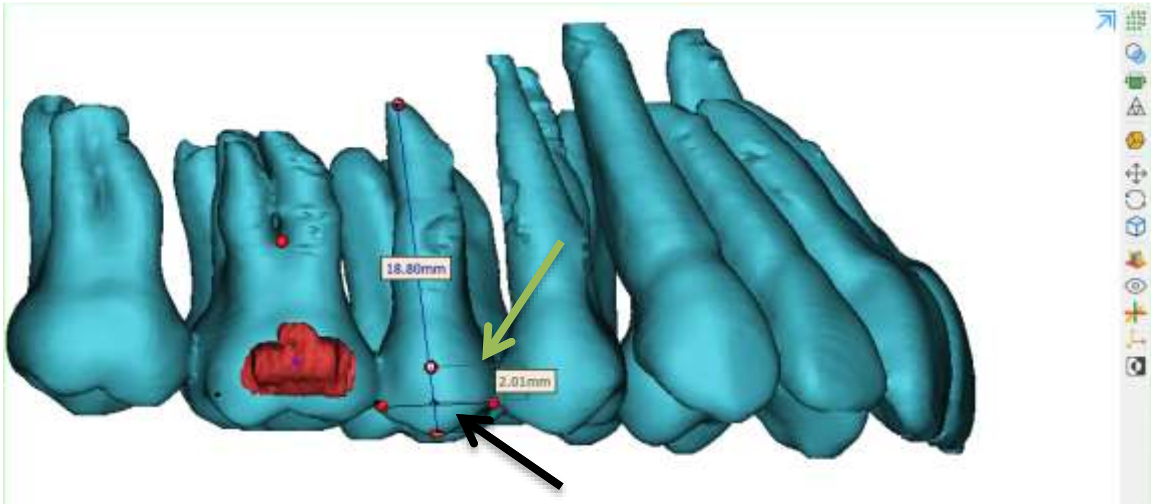

Fig3. Connect marginal ridge line and detect slot line far away from marginal ridge line by 2 mm. Green arrow points slot line. Black arrow points marginal ridge line

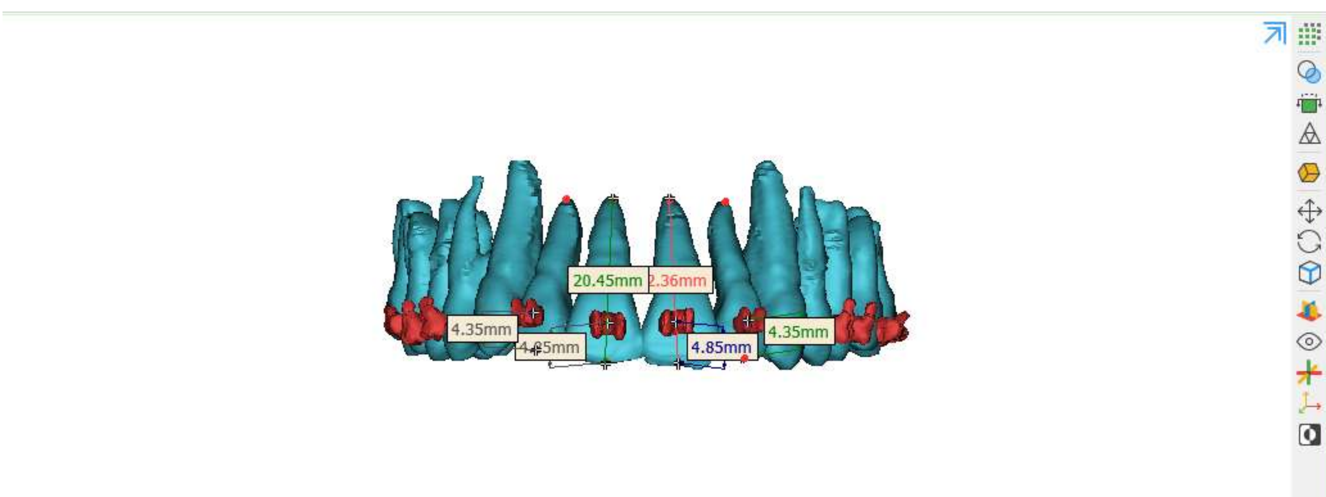

Fig4. Anterior bracket positioning after detect their vertical position.

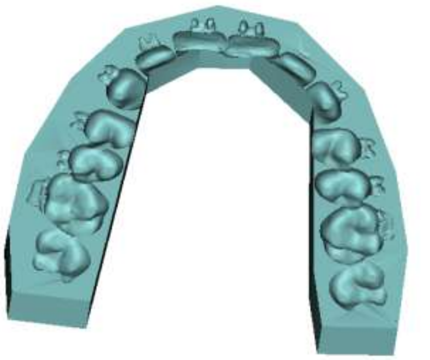

Fig5. Final shape of tray after subtraction teeth and bracket.

Fig6. Actual brackets inserted into bonding tray.

Fig7. Patient preparation.

Fig8. Frontal lateral intraoral view after tray insertion.

Fig9. Occlusal view after tray removal.

6. Intra-oral scanning and assessment.

Intraoral scanning for each patient was performed after bonding by using intra oral scanner- Medit i 700 Scanner made in South Korea- to get STL file [fig 10].

With STL file of each patient after bonding in Mimics software vertical bracket height of each tooth from first molar from one side to the other side's first molar was measured.

The new measurement was obtained posteriorly from occlusal surface to center of each bonded bracket and anteriorly was obtained from incisal edge to center of bracket [fig 11]. The data was collected and statically analyzed to assess accuracy of vertical height transfer by the new technique.

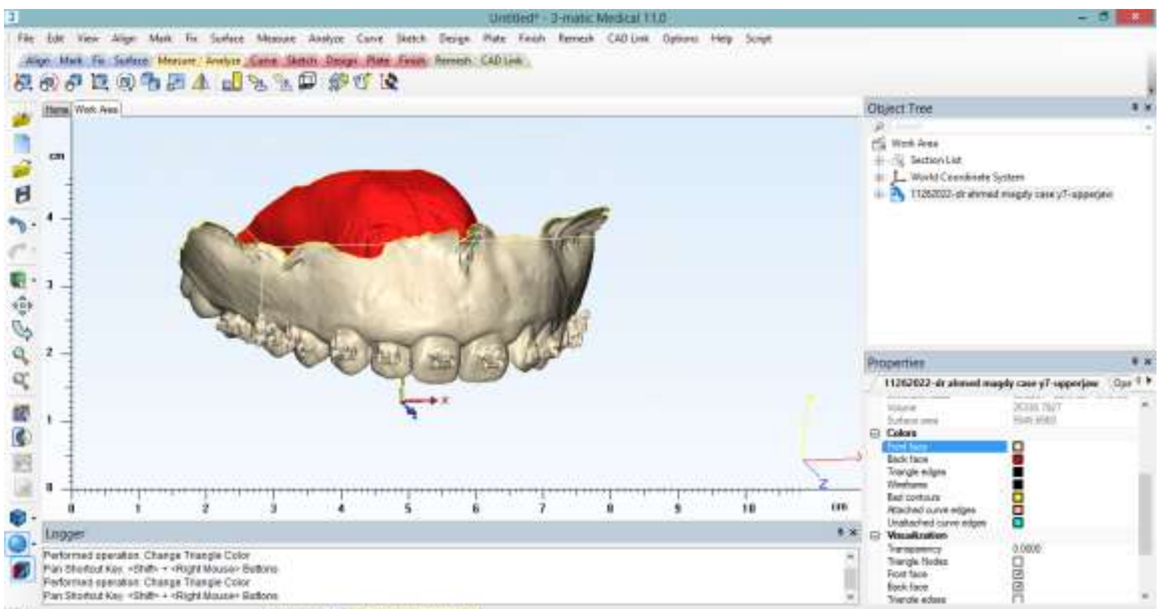

Fig10. STL file of patient scanning after bonding.

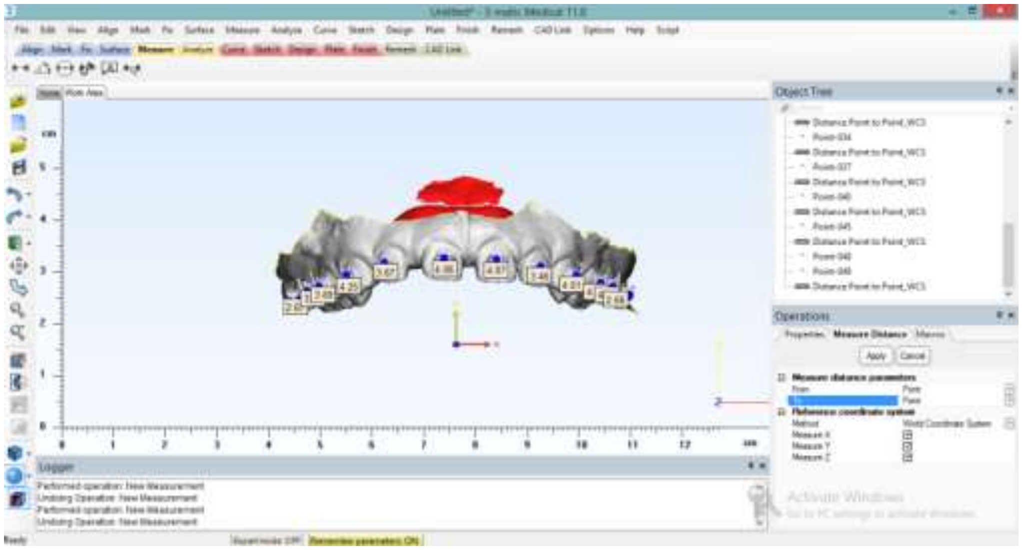

Fig11. Vertical assessment after bonding (Frontal view).

Results: Regarding accuracy assessment of vertical position reliability, consistency and level of agreement were measured.

A. Reliability and consistency

Intra-class correlation coefficient (ICC) was (> 0.9) with p value < 0.001*, donating excellent reliability between standard and the new methods.

Cronbach's alpha calculated (> 0.9) with p value < 0.001*, indicating excellent Internal consistency between the two methods, also [Table 1].

Intra- class correlation coefficient of lateral incisors, canines and premolars was detected (0.75<ICC<0.9) with p value < 0.001*, this indicates good reliability between the standard and new digital method.

When assessing the internal consistency (Cronbach's alpha) between the two methods, a good internal consistency was detected among premolars and laterals incisors between the (0.8<α< 0.9) with p value < 0.001*.

However, Acceptable internal consistency (Cronbach's alpha) was found among centrals incisors, canines and molars (0.7<α< 0.8) with p value < 0.001*[Table 2].

Concerning centrals & molars groups, Intra- class correlation coefficient was (0.7<ICC <0.75) with p value < 0.001*. So, there was acceptable reliability between the standard and new digital method [Table 2].

	Cronbach's alpha	ICC	P value
Vertical bracket position (Standard vs. new)	0.903	0.903	***<0.001****

Table1. Intra- class correlation and internal consistency between the standard and the new digital technique for 120 units.

Vertical bracket position (Standard vs Digital)	Cronbach's alpha	ICC	P value
Central incisor	0.748	0.748	***<0.001****
Lateral incisor	0.822	0.822	***<0.001****
Canine	0.778	0.778	***<0.001****
Premolar	0.817	0.817	***<0.001****
Molar	0.728	0.728	***<0.001****

Table2. Shows intra- class correlation and internal consistency between the standard and the new digital technique in each group separately.

B. Level of agreement

1. **Bland Altman plot [fig 12,13,14,15,16,17]:**

For lateral incisors, canines and premolars groups Simple linear regression analyses for Vertical bracket height showed no statistically relevant. This parameter **is not exhibited proportional bias** with p value =0.068, 0.706 and 0.794 in order. Although the results were encouraging, Simple linear regression analyses for Vertical bracket position for central incisors and molar groups showed statistically relevant bias by P value 0.047 *, 0.019* in order the parameter **is exhibited proportional bias.** The mean differences range of the five groups was (0.002:0.175) mm [table 3]. No statistical significant difference P value (0.185) was found between the five groups regarding to Kruskal Wallis test [table 4].

However, Simple linear regression analyses for Vertical bracket height showed no statistically relevant p-value (p = 0.089). This parameter **is not exhibited proportional bias** for the total sample[table 5].

2. **Pearson's correlation coefficient between the 2 methods [Table 3]:**

Positive strong significant correlation was detected for the total sample and for each group.

Standard method vs Digital new method	**Bland-Altman Plot**			**Pearson's correlation**		**Paired Samples T test**			
	Limits of agreement		**P value (linear regression)**	**r**	**P value**	**Mean difference**	**95% CI of Mean difference**		**P value**
	Lower	**Upper**					**Lower**	**Upper**	
Vertical bracket position	-0.5	0.71	*0.089*	0.826	***<0.001****	-0.105	-0.16	-0.05	***<0.001****

Table3. Bland-Altaman plot, Pearson's correlation and paired T test results for all 120 units.

Vertical bracket position		**Central incisor**	**Lateral incisor**	**Canine**	**Premolar**	**Molar**	**P value**
		N=20	**N=20**	**N=20**	**N=40**	**N=20**	
Mean differences	*Range*	(-0.5-0.5)	(-0.3-0.6)	(-0.4-0.6)	(-0.6-0.6)	(-0.6-0.6)	*0.185*
	Mean ± SD	0.1±0.3	0.2±0.3	0.2±0.3	0.0٢±0.3	0.2±0.4	
	Median	0.2	0.15	0.09	0.03	0.07	

Table 4. Kruskal Wallis test compares between mean differences of five groups

Standard method vs Digital method									
Vertical bracket position	Bland-Altman Plot			Pearson's correlation		Paired Samples T test			
	Limits of agreement		P value (linear regression)	r	P value	Mean difference	95% CI of Mean difference		P value
	Lower	Upper					Lower	Upper	
Central incisor	-0.44	0.73	***0.047****	0.640	***0.002****	-0.144	-0.28	-0.004	***0.043****
Lateral incisor	-0.32	0.67	*0.068*	0.731	***<0.001****	-0.175	-0.29	-0.06	***0.006****
Canine	-0.35	0.65	*0.706*	0.638	***0.003****	-0.154	-0.27	0.04	***0.013****
Premolar	-0.64	0.64	*0.794*	0.691	***<0.001****	-0.002	-0.11	0.1	*0.969*
Molar	-0.54	0.84	***0.019****	0.633	***0.003****	-0.152	0.32	0.01	*0.069*

Table5. Bland-Altaman plot, Pearson's correlation and paired T test results between the two methods for the four groups.

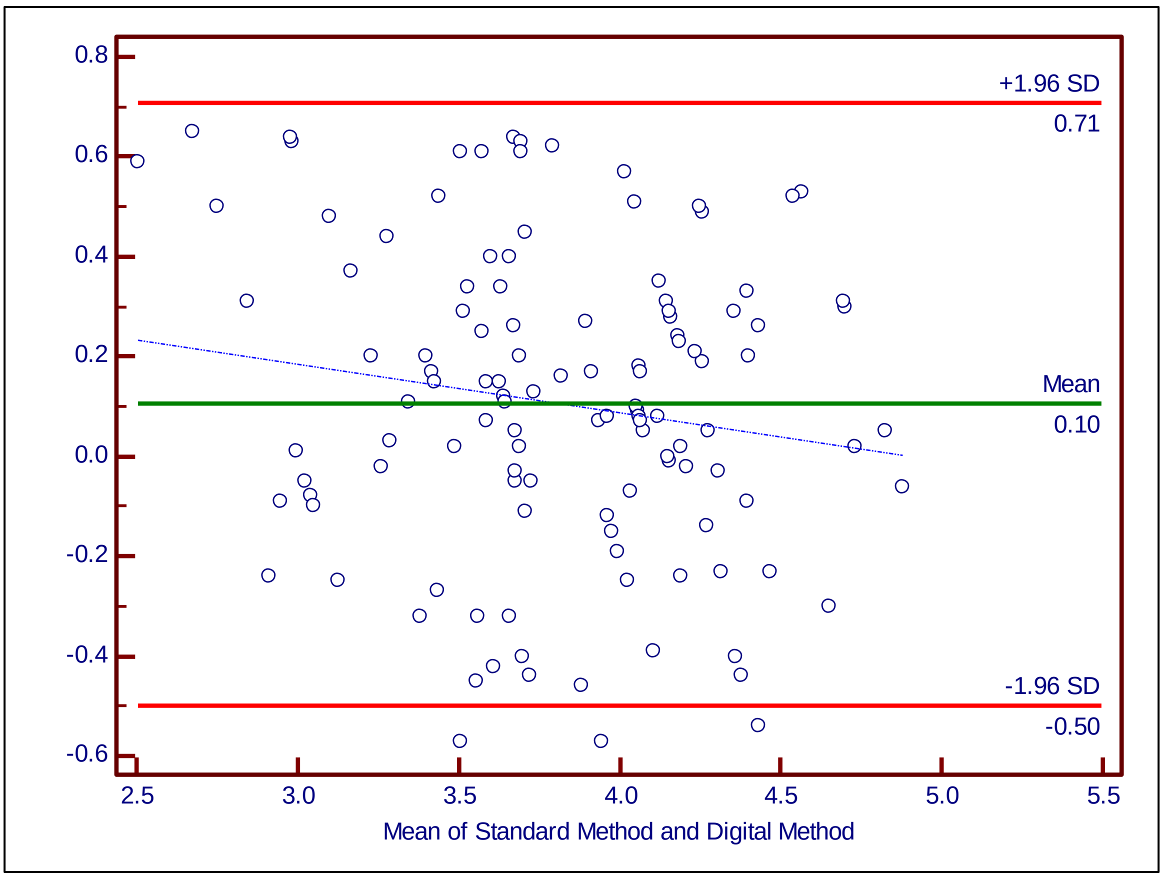

Fig12. Bland Altman plot of agreement between the slandered and new digital method (120 Units).

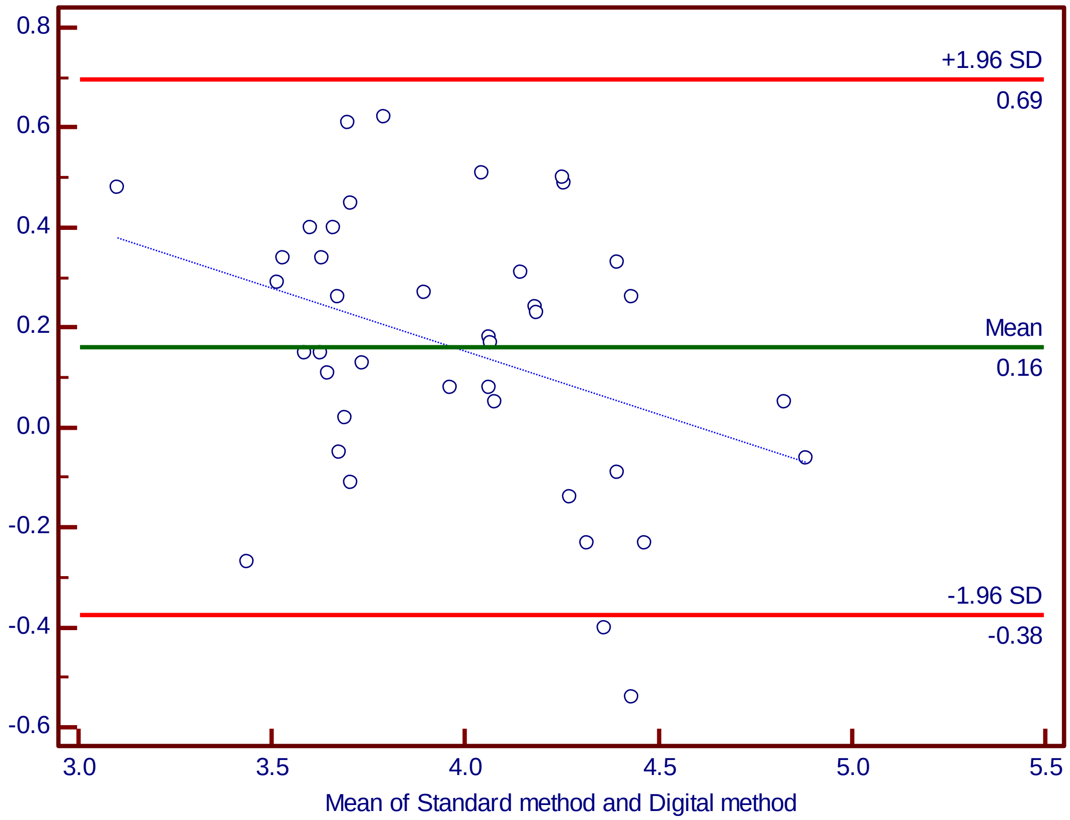

Fig13. Bland Altman plot of agreement between the slandered and new digital method for central incisors group.

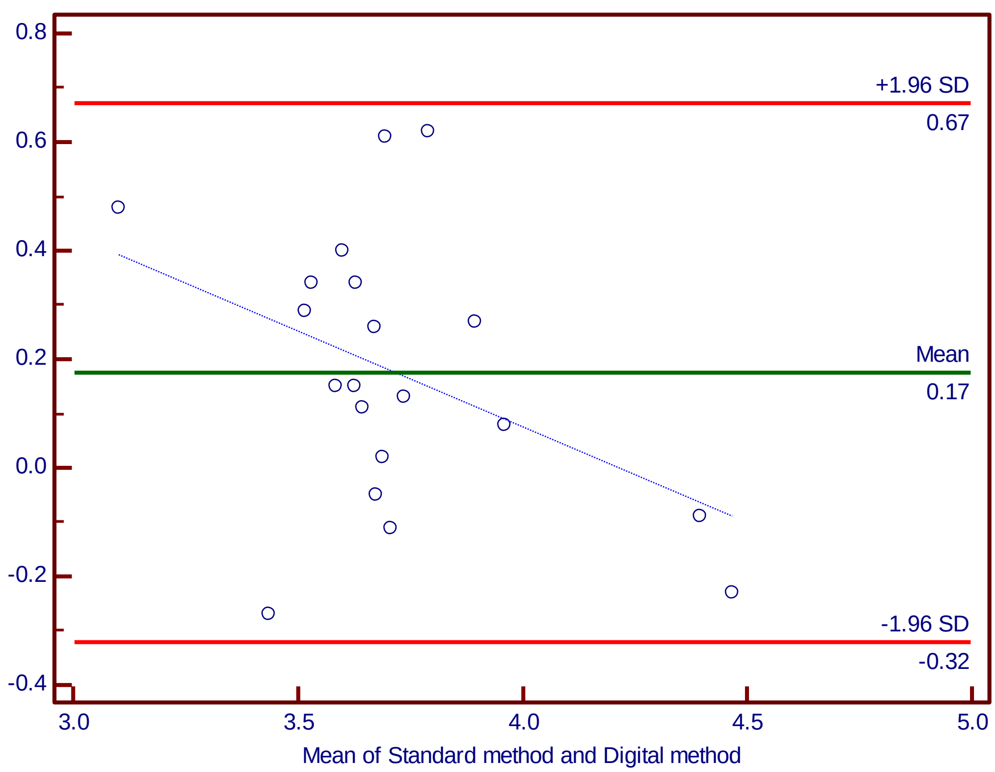

Fig14. Bland Altman plot of agreement between the slandered and new digital method for lateral incisors group.

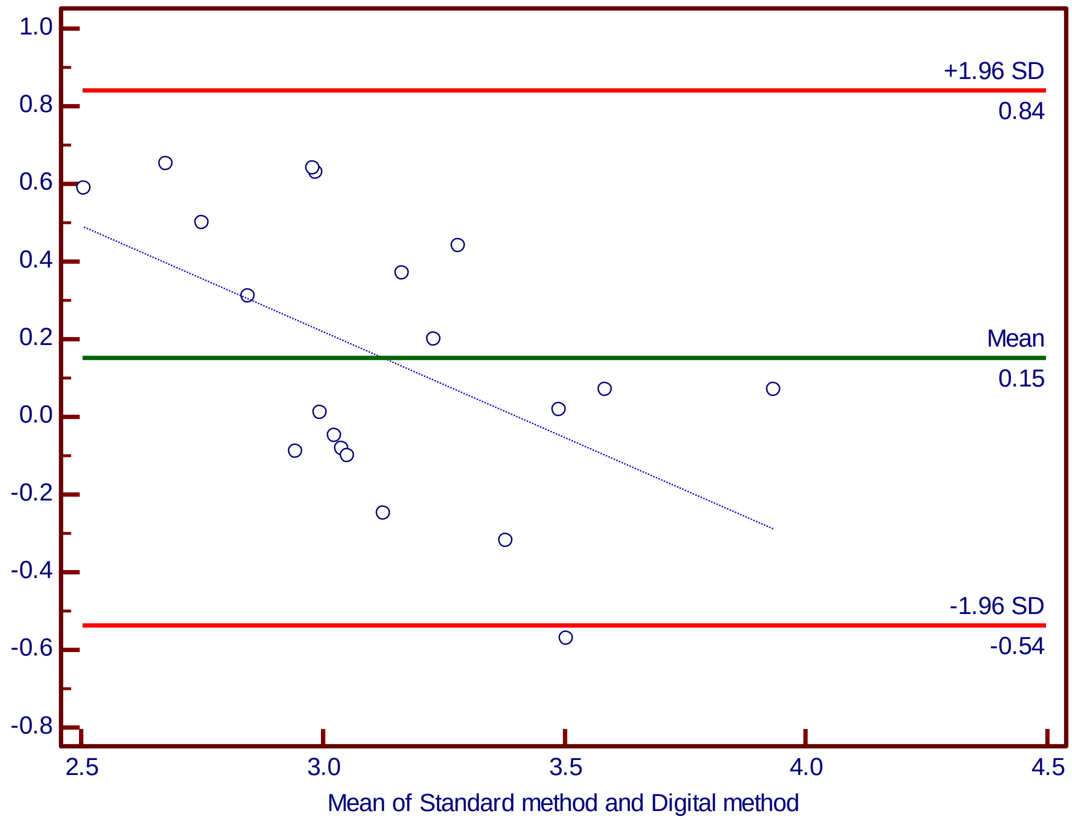

Fig15. Bland Altman plot of agreement between the slandered and new digital method for canines group.

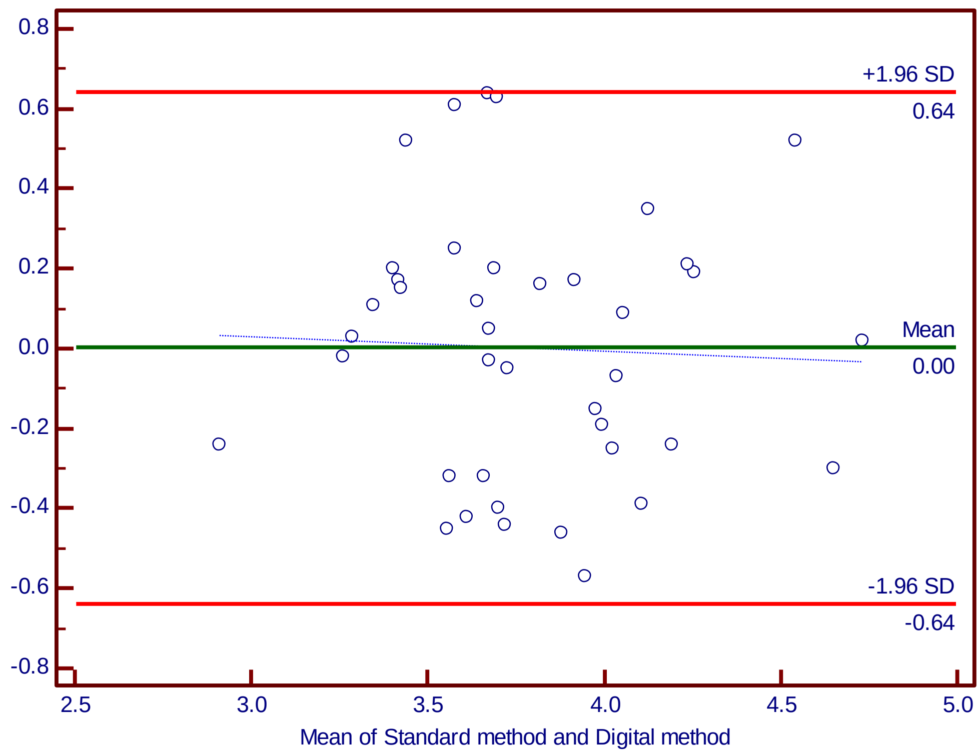

Fig17. Bland Altman plo

Fig16. Bland Altman plot of agreement between the slandered and new digital method for premolars group.

Discussion

Bracket positioning is one of the most important corners of successful orthodontic treatment. Accordingly, many studies compete to create, innovate and develop techniques to increase accuracy of bracket positioning by reducing the error of the human factor, until reach the most accurate, the cheapest, the easiest and the reproducible technique and more confortable to the patient.

Direct bonding of brackets was begun in 1960s using chemically cured adhesive **(Nawrocka A)[7]**. That was a revolutionary change especially in border line extraction case which provided space of 12 or 14 bands thickness to treat border line cases without extraction **(newman1995)[8]**. In the direct bonding, we don't grantee patient cooperation or total elimination human factor fault. There were many trials to reduce the fault of human factor of practitioner and decrease the needs for patients' cooperation due to presence of many factors related to the patient and the orthodontist affect accuracy of bonding directly to the patient mouth.

The innovative of indirect bonding technique was developed 1972 by Silvermann as a trial to improve precision of bracket position by using working cast to fabricate a transfer tray **(Silvermann 1972)[9]**. One of the main disadvantages was being a very sensitive technique and the steps must be followed closely**. (Thomas 1979)[10]**

Indirect bonding defined as preparation bracket position by mean far away from the patient, and then the bracket position was transferred to the patient by tray **(kalange and Thomas 2007)[11].** This was ensuring more accuracy and decrease patient time to provide more comfortable treatment **(kalange and Thomas 2007)[11].** Many trials were performed to improve indirect technique to overcome the shortage of each other by increase accuracy of transfer, decrease cost, easily reproducible and elimination any sensitivity in technique.

That was done by trying different tray materials; polyvinyl trays, vacuum formed trays and trays from different types of resin vary in techniques began by using model cast to printed cast and then full digital technique. With revolution of the technology, full digitalization of indirect bonding is necessary to increase accuracy and eliminate the lab techniques limitations.

In this study, a new full digitalized indirect technique was used; the aim was to assess the accuracy of vertical transfer of brackets by the new technique. This study is double tailed clinical trial to evaluate if the new digital technique will be clinically accepted or not. Maximization of accuracy and simplify the technique were our priority.

A ten patients were included in this study had upper arch bonding by the new indirect technique. A suitable sample size calculation was carried out to estimate the total unit with a good precision by using an appropriate equation according to **Suresh KP, et al 2012[6].**

The digitalization of the brackets was held through CBCT imaging and the image was segmented to get STL file. This was tried by **El-Timamy AM, et al 2016 [12]**, who only believed that the CBCT technology not used only as a diagnostic aid but also a treatment aid. In his work, he didn't mention the detailed parameters and detailed method for how digitalization the brackets.

Modified kalange method was used for digital bracket position which goes with **De Lima DV et al 2020 [13]** to get better function and esthetics. This was used as standard measurement for brackets position. Magnification was used to ensure intimate contact between teeth and brackets digitally.

DLP printing technique is used in this study which gives sufficient accurate printed tray. That was not consistent with **El-Timamy AM, et al [12],** which used SLS as printing technique in his work. **Christensen LR, et al [14]**stated that any SLA or DLP dental printer with a sufficient resolution can be utilized to create the bracket transfer model. To yet, we had not been successful in printing biocompatible soft trays using SLA printers. Only DLP printers had been able to do this up until now. They had not been able to print trays with precise enough bracket architecture to do away with the necessity for digital block out, not even with relatively high-end DLP printers.

Francois Rouz´e l'Alzit, et al [15] concluded the 3D printing technology (SLA/DLP) has a limited impact on 3D printed surgical guides' accuracy. However, the size of the guide can have a significant Impact, as small-extent guides were more accurate than large-extent guides. SLA, DLP and Polyjet® technologies showed similar results in terms of trueness and precision for both small-extend and large-extend guides. DLP printers can accurately be used to print dental models for the fabrication of orthodontic appliances **Tsolakis IA, et al 2022[16]**.

Reliability and internal consistency was found (ICC>0.9) with p value < 0.001* and agreement between standard and new technique showed P value =0.089 in total 120 units. Reliability and internal consistency was (ICC>0.8), (0.75<ICC<0.8) and (0.7<ICC<0.75) for lateral incisors and premolars groups, canines group and central incisors and molars groups, respectively.

There is agreement in lateral incisors, canines and premolars groups with p value =0.068, 0.706 and 0.794 in order. Although the results were encouraging, there was proportion bias in central incisors and molar groups by P value ***0.047*** *, ***0.019**** in order. The mean differences range of the five groups was (0.002:0.175) mm. according Kruskal Wallis test there is no statistical difference P value = 0.185.

The most frequent linear errors for the 3D-printed IDB tray were discovered in the vertical dimension towards the occlusal, regardless of the material used or the production technique, Similar to the conclusions of **D'orfer et al [17]** and **Schmid et al [18]**.

Since the 3D-printed tray is of hard consistency and does not have defined areas of different elastic properties as suggested by **Jungbauer et al [19],** anterior teeth and molars accuracy transfer more affected. Better transfer results may be achieved using more materials of different elastic properties and an adapted tray design, **Eva C. Hofmann et al 2022 [20].**

The mean difference range (0.002: 0.175) mm which was much less than 0.5 mm was clinical insignificant. As there are no evidence-based limits for clinically acceptable bracket position deviations in the literature, most studies refer to the professional standards of the American Board of Orthodontics of 0.5 mm for linear and 2 degree for angular deviations[21-22]. So, vertical bracket transfer was accurate for all groups.

Our results showed excellent reliability and internal consistency for the new technique as general. High level of agreement was found with mean difference clinically accepted. For the five groups, there was good reliability for lateral incisors, canines and premolar and acceptable for central incisors and molars group. There was high agreement for lateral incisors, canines and premolars groups. In the other hand, central incisors and molars groups show proportional bias. However the mean differences of all group clinically accepted.

Conclusion

This protocol transferred the planed vertical brackets position from the virtual setup to the patient was generally highly accurate and reliable technique.

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