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ACCURACY OF 3D PRINTING VERSUS MILLING IN FABRICATION OF CLEAR ALIGNERS DENTAL MODELS

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ABSTRACT

Objective: This study was conducted to compare two techniques for fabricating dental models with attachments (additive 3D printing versus subtractive milling). **Materials and Methods**: a random model was selected and scanned with an intraoral scanner Medit I600 and the STL file of the model was used to create another STL file of a new model with rectangular attachments on the labial and buccal surfaces of the anterior and posterior teeth respectively was created by Maestero software. The new STL file was 3D printed three times by the same 3D printer (Anycubic mono X) to produce 3D printed models that consitituted group 1. Three 3D printed discs were created by the same 3D printer with dimensions matching the discs of the milling machine. Group 2 consisted of three milled models that were fabricated by a milling machine ROLAND 51 (Kemet corporation, Cairo, Egypt). The models of both groups were scanned with the same intraoral scanner Medit I600, and the STL files generated were superimposed over the original STL file by the same software (cloudcompare). The linear deviations of attachment position, measured in millimeters, were as follows; A) Mesio-distal: The X-axis movement B) Occluso-gingival: The Z-axis C) Bucco-lingual: The Y-axis movement. One way ANOVA and t tests were used to compare the deviation within each group and between the two groups, the significant level was set at $p\text{-value} \leq 0.05$. **Results:** statistically significant differences between the molars, incisors, canines, and premolars were observed in both groups in all ways of space. Comparing the two groups revealed a non statistically significant difference between both groups. **Conclusion:** 3d printing provided a more economic and less time and material wasting way for fabrication of clear aligners models with attachments than milling.

KEY WORDS: 3D printing, Milling, Digital Models, Clear Aligners, Attachments.

INTRODUCTION

With the recent increase in adults seeking orthodontic treatment, the esthetic demand is necessary as adults usually need an orthodontic appliance with high esthetic and less painful intervention. Clear aligners meet these needs, providing a high esthetic device with minimal patient pain and discomfort (1). Aligner therapy has significantly changed from its inception in the 1970s. The wide spread of CAD/CAM systems in industry and their application in dentistry revolutionized aligners production. These changes coped with advances in software packages which facilitated the treatment of patients with various complexity of care. Several software, Intraoral scanners, and 3D printers with affordable prices are available in the market, which allows orthodontists to plan and fabricate their clear aligners. Clear align-

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ers fabrication involves three main steps; planning, 3D printing, and pressing the transparent aligners sheets on the 3D printed models (2).

As previously reported in the literature, clear aligner therapy often requires the use of auxiliaries (attachments, altered aligner geometries, inter-arch elastics, etc.) to improve the efficacy of orthodontic movement (1,3). Attachments are force transducers that seem to improve the biomechanics of invisible aligners. Attachments are a protrusion of composite material polymerized onto the tooth surface, applied to enhance aligner retention and obtain orthodontic movements previously considered critical to achieving. They can reach these goals by strengthening the mismatch in specific points, improving the contact area, and improving the force system application (4,5).

3D printing is the backbone of clear aligners fabrication. Several 3D printers with different technologies are available, but SLA is most commonly used because of their high printing resolution and fast-forming speed (6). SLA uses a liquid resin and solidifies it with ultraviolet light. The problem with this solidification is that it is usually accompanied by polymerization shrinkage, which consequently causes dimensional changes. The dimensional changes affect the printed models' Accuracy, which affects the pressed aligners' Accuracy (7).

Little research has been reported regarding the Accuracy of 3D-printed models for orthodontic applications. Most of the literature compared linear measurements of 3D-printed models with those of stone models (8–10). Zhang et al. (11) compared two types of 3D printers, DLP and SLA, at different thicknesses and found that the printing accuracy was higher at 50 µm of all the printers. Park and Shin (12) compared 3d printed models with conventional casts and found that the 3D printed models had greater dimensional changes than traditional dental casts. However, Brown et al. (13), who compared 3d printed models with stone models, found that teeth measurements and arch parameters were similar in all groups. Linear measurements on printed models were slightly less accurate than those performed on plaster models (in a range between 0.20 and 0.30 mm) (9,14). However, this difference was in the range of clinical acceptance and similar to the reliability error determined for manual measurements (15,16). Consequently, prototyped models are considered accurate enough for orthodontic study models.

Milling is an alternative method for manufacturing 3D objects. It involves carving the desired object on solid discs. Several studies (17–20) compared the two technologies, 3D printing, and milling, in the fabrication of zirconia crowns, inlays, and Onlays, and complete and partial dentures. The results of these studies were variable, as some authors reported that the Accuracy of 3D printing varies widely between and within laboratories but lies within the range of Accuracy of conventional manufacturing methods (17). On the other hand, others said that milling was more accurate than 3D printing (18,20). No previous studies compared the two technologies in fabricating clear aligners models with attachments. Therefore, this study was conducted to compare the Accuracy of 3D printed models with attachments with those manufactured by a milling machine.

MATERIALS AND METHODS

Sample size calculation:

The study was conducted on six models, three in each group. The sample was calculated according to Arkin 1984 using the following equation:

$$N=(\boldsymbol{Za})\mathbf{2}\times(\boldsymbol{SD})\mathbf{2}/(\boldsymbol{d})\mathbf{2}$$

N = Total sample size.

Za = Is standard normal variate, and its equal 1.96 at P < 0.05.

SD = Standard deviation of variable.

d = Absolute error of precision.

The criteria used for the sample size calculation were as follows: Confidence limit of 95 %, Power of the study of 80 %, Significance level of 0.05, mean difference of 0.1, and standard deviation of differences of 0.15. These data were obtained from a pilot study. The 1ry outcome used was the combined XYZ deviation of the attachments in the anterior and posterior segments. The equation revealed a total number of 34 teeth in each group, and the number was increased to 52 in each group to improve the study's validity.

A random maxillary cast was selected and digitally scanned using an intraoral scanner (Medit I 600, Medit, medit.com). Next, the model STL file was imported to Maestro digital software (Maestro 3D dental studio, version 5.2). Then, rectangular attachments were added to the labial surfaces of the anterior teeth and the buccal surfaces of the premolars and molars. The attachments were added in the following manner; a single attachment was added to the middle of the middle third of each tooth from the central incisor to the 2nd premolar. In addition, two attachments were added to the middle of the middle third of the buccal surface of each cusp of the molars, one for each cusp. The attachment dimensions were: 2 mm in width, 3 mm in height, and 1 mm in thickness **(Fig. 1)**. The total number of attachments on each cast was 18 attachment. Finally, the STL file of the model with the attachments on it was exported to the specific folder on the computer device. This STL file was 3D printed to give three models representing Group I and milled three times to provide three models representing Group II.

Disc preparation:

The STL file of the disc used in the milling was constructed by 3D Builder software (Microsoft Corporation, version 18.0.1931.0) **(Fig. 2 a)**. The diameter of the disc was 100 mm, and the thickness was 16 mm. two rims were created on the upper and lower edges of the disc by engraving in the upper and lower edges of the disc to facilitate its engagement in the milling machine. Each trim was 2 mm in height and 2 mm in width. The vertical distance between the two edges was 10 mm. Then, the STL file of the disc was exported to the specific folder on the computer.

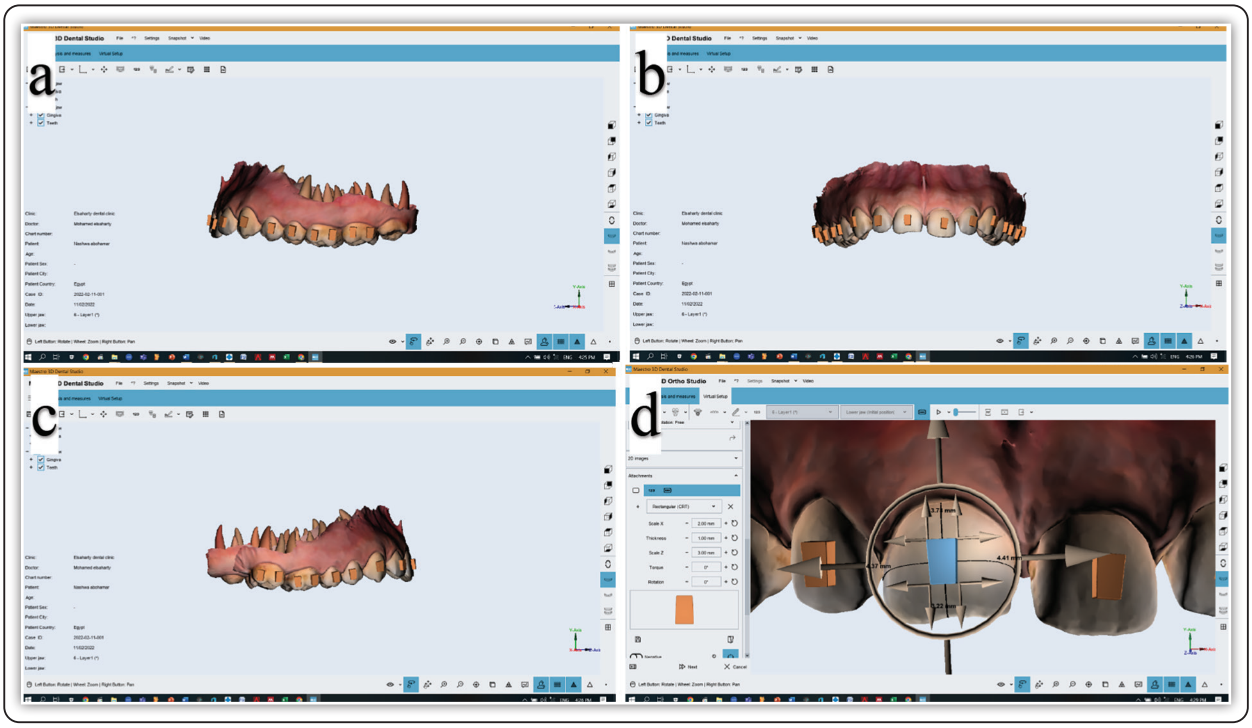


FIG (1) a) left side view of the upper model with attachments b) frontal view c) right side view d) the dimension and position of the attachment on the software.

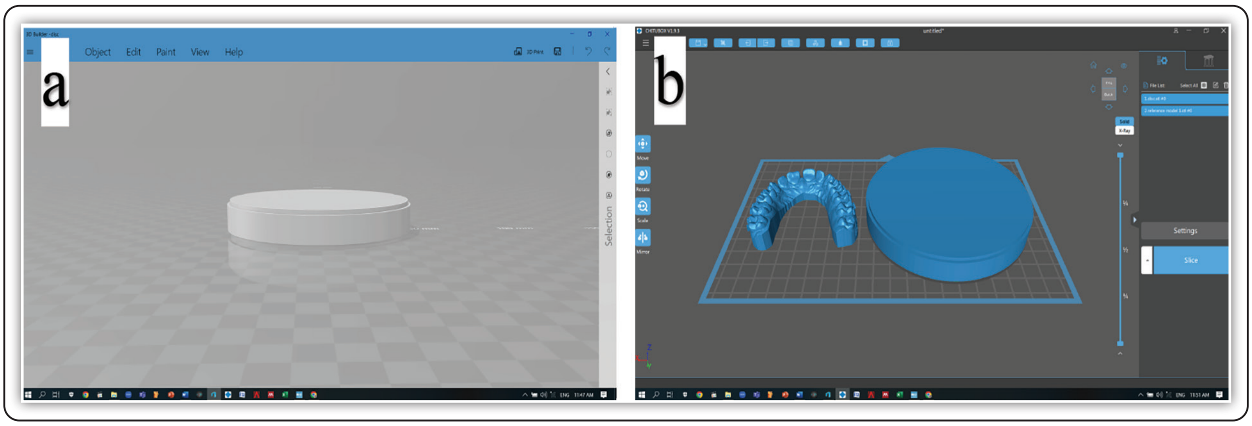


FIG (2) a) The disc designing on the 3D builder software, b) the disc and the model slicing by the Chitubox software.

3D printing:

The first step in 3D printing was transforming the STL file into a sliced file to allow the 3D printer to deal with it. The software used in this study was CHITUBOX Basic (CBD Technology Corporation, LTD, Version 1.9.3) **(Fig. 2 b).** The STL files of the reference model with attachments on it and the disc were imported into the software; the two objects were set to be horizontal on the forming plate. The type of 3D printer was selected on the software to be Anycubic Photon Mono X, as this SLA 3D printer was used in this study. The resin used in this study was Mammoth resin for models (PLA Pro Resin, Gray, 2-4 s/0.5 m, V Ceram corporation, Egypt). The printing criteria were adjusted to be: layer thickness 0.05 mm, bottom layer count 6, bottom layer exposure time 20 sec, and standard exposure time 3 sec for all layers. Finally, the two objects were sliced, and a new file with (*pwmx) extension was created and added to a data traveler to be inserted in its socket in the 3D printing machine.

The second step in 3D printing was leveling the plane of the forming plate to make it touch the 3d printer screen at all its points. A sheet of paper was put above the printers screen, then loosening the screws of the forming plate, then moved its holder on the vertical rail till it touched the sheet of paper at all the points; this can be confirmed by the inability to move the sheet of paper between the plate and screen **(Fig. 3 a)**. Screws were tightened, and this position was recorded as the Zero position **(Fig. 3 b)**. Then the plate was raised, the resin tank with the 3D printing resin was returned to its position on the screen of the 3D printer, and 3D printing started **(Fig.3 c&d)**.

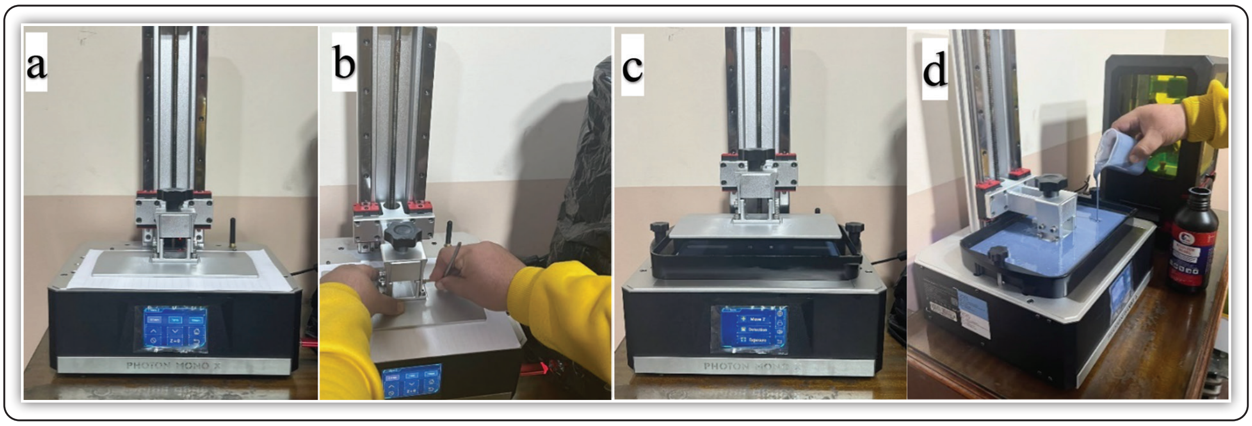


FIG (3) a) leveling of the 3D printer forming plate, b) screw tightening, c) resin tank was returned to its position. d) resin was poured into the tank

The third step in 3D printing was the removal of the objects from the forming plate, then washing them with isopropyl alcohol washes at a 95% concentration in two separate containers to remove resin residues, followed by a 15-minute UV-light post-curing exposure to cure any residual monomer. Finally, the disc was ready for milling, and the 3D-printed models were prepared for scanning **(Fig.4 a&b)**.

3D milling:

The STL file of the reference model was manipulated by the software Millbox (CIM system corporation, version 2018) to be prepared for milling. The milling machine used in this study was ROLAND 51 (Kemet corporation, Cairo, Egypt). After milling, the model was removed from the disc and ready for scanning.

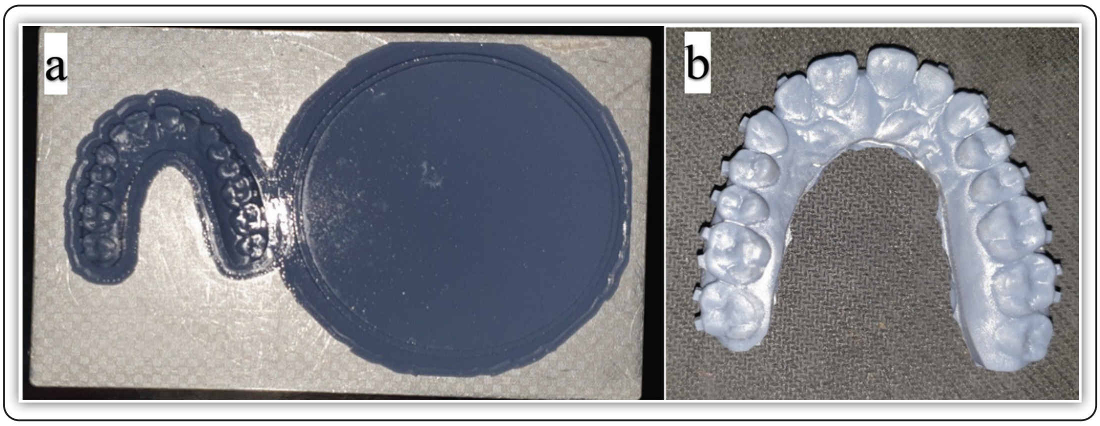


FIG (4) a) the 3D printed model and disc, b) the 3D printed model with attachments after washing

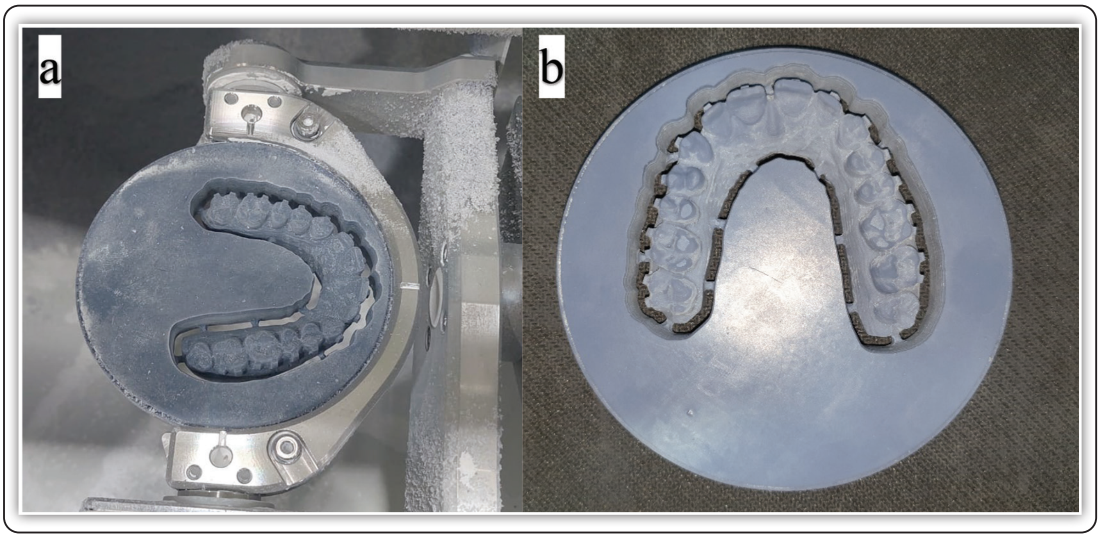


FIG (5) a) the 3D printed disc in the milling machine after milling of the model, b) the 3D printed disc after removal from the milling machine.

Model scanning:

The scanner used in this study was Medit I 600 (Kemet corporation, Cairo, Egypt, Medit, medit.com). First, both groups were scanned by the same operator and the same scanner, then STL files of both models were obtained.

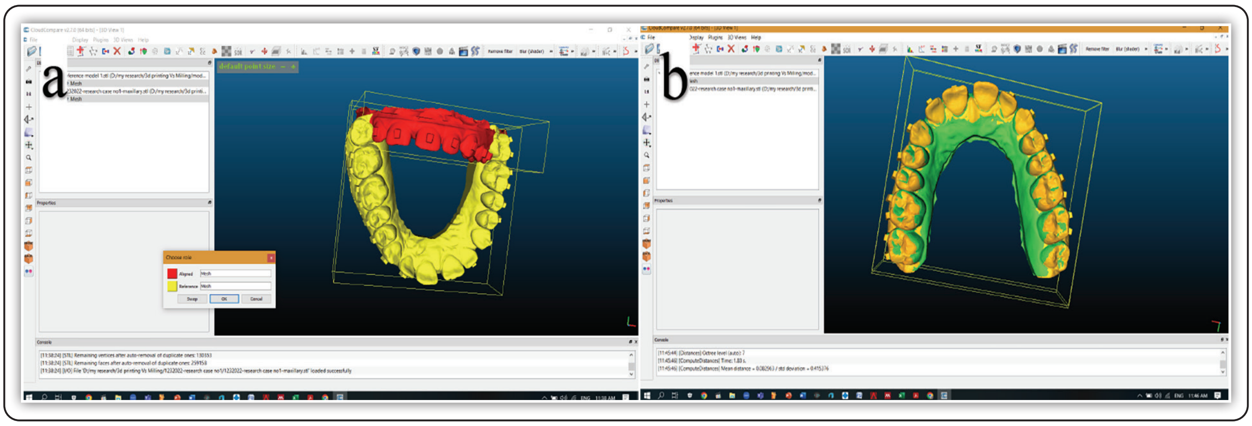
Superimposition:

In both groups, the master model obtained after virtual planning on Maestro digital software (Maestro 3D dental studio, version 5.2) served as a reference record. In contrast, the STL files of the 3D printed models (group I) and the milled models (group II) were considered the test models. The STL files were prepared and superimposed using Cloud compare software **(Fig. 6 a&b)**. The best-fit algorithm was used for the surface area of the models; more evenly distributed colors indicated a good surface match, whereas isolated colors indicated a poor surface match. The X, Y, and Z-axes were manually added to each attachment creating a local coordinate system in reference and test records in both models. The X-axis represented the mesiodistal dimension, the Y-axis represented the buccolingual dimension, and the Z-axis represented the occlusal-gingival dimension. The deviations between reference and test STL files in both models were quantified to the local coordinate systems in three linear values (millimeters) along the axes X, Y, and Z.

The linear deviations of attachment position, measured in millimeters, were as follows; A) Mesio-distal: The X-axis movement was monitored; distal translations had positive numbers, while mesial translations had negative values. B) Occluso-gingival: The Z-axis movement was monitored; gingival translations were reported as positive and occlusal translations as negative numbers. C) Bucco-lingual: The Y-axis movement was monitored; negative numbers were given to lingual translations, whereas positive numbers were to buccal translations.

Statistical analysis

All the measurements of 104 attachments (52 for each group) were collected, tabulated, and statistically analyzed at the end of the study using the software SPSS, version 25. A paired sample t-test was used to compare the deviations between both groups in all linear aspects. Also, comparing both groups according to tooth type (incisors, canines, and premolars) on the mean of linear deviations was performed using a paired sample t-test. One Way ANOVA was used when indicated.



```
[11:38:24] [STL] Remaining vertices after auto-removal of duplicate ones: 130353
[11:38:24] [STL] Remaining faces after auto-removal of duplicate ones: 259158
[11:38:24] [I/O] File 'D:/my research/3d printing Vs Milling/1232022-research case no1/1232022-research case no1-maxillary.stl' loaded successfully
```

```
[11:45:44] [Distances] Octree level (auto): 7
[11:45:46] [ComputeDistances] Time: 1.83 s.
[11:45:46] [ComputeDistances] Mean distance = 0.082963 / std deviation = 0.415376
```

FIG (6) a)& b) model superimposition on Cloudcompare software

RESULTS

TABLE (1) Sample distribution according to the technique of printing.

	Group I	Group II	Total
Model number	3	3	6
Attachment number	52	52	104

TABLE (2) Sample distribution according to tooth type.

Tooth type	Group I	Group II	Total
Incisors	12	12	24
Canines	6	6	12
Premolars	12	12	24
Molars	24	24	48

TABLE (3) Comparison between both groups according to tooth type in XYZ planes (mm)

Tooth type	Group I Mean + SD	Group II Mean + SD	t-test value	P value
Incisors (24)	0.24 + 0.022	0.23 + 0.193	1.000	0.339
Canines (12)	0.23 + 0.021	0.21 + 0.021	1.467	0.202
Premolars (24)	0.27 + 0.040	0.26 + 0.043	1.483	0.166
Molars (48)	0.49 + 0.038	0.48 + 0.041	1.318	0.21

**. The mean difference is significant at the 0.05 level.*

TABLE (4) Comparison between both groups according to tooth type in occluso-gingival plane (mm)

Tooth type	Group I Mean + SD	Group II Mean + SD	t-test value	P value
Incisors (24)	0.150 + 0.012	0.153 +0.020	-0.07	0.946
Canines (12)	0.115 + 0.027	0.113 + 0.026	0.415	0.695
Premolars (24)	0.109 + 0.054	0.093 + 0.045	1.036	0.322
Molars (48)	0.107 + 0.044	0.109 + 0.046	0.000	1.000

**. The mean difference is significant at the 0.05 level.*

TABLE (5) Comparison between both groups according to tooth type in Mesio-distal plane (mm)

Tooth type	Group I Mean + SD	Group II Mean + SD	t-test value	P value
Incisors (24)	0.0907+ 0.041	0.0692+0.028	2.714	0.020
Canines (12)	0.185+0.035	0.185+0.034	1.581	0.175
Premolars (24)	0.1942+0.084	0.1917+0.078	0.821	0.429
Molars (48)	0.2508+0.104	0.2513+0.106	-0.089	0.930

**. The mean difference is significant at the 0.05 level.*

TABLE (6) Comparison between both groups according to tooth type in Bucco-lingual plane (mm)

Tooth type	Group I Mean + SD	Group II Mean + SD	t-test value	P value
Incisors (24)	0.162 +0.032	0.154 +0.048	0.566	0.582
Canines (12)	0.031 +0.009	0.132 +0.122	-2.001	0.102
Premolars (24)	0.110 + 0.072	0.125 +0.081	-1.528	0.155
Molars (48)	0.372 +0.052	0.383+ 0.051	-2.200	0.038

**. The mean difference is significant at the 0.05 level.*

TABLE (7) Comparison between deviations in the molar, incisors, canines, and premolar areas in group 1 (3d printing) ANOVA test:

XYZ deviation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.804	3	.268	228.967	.000**
Within Groups	.059	50	.001		
Total	.862	53			

X deviation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.206	3	.069	9.982	.000**
Within Groups	.344	50	.007		
Total	.550	53			
Y deviation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	.949	3	.316	114.883	.000**
Within Groups	.138	50	.003		
Total	1.087	53			
Z deviation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	.016	3	.005	3.183	.032*
Within Groups	.084	50	.002		
Total	.100	53			

**. The mean difference is significant at the 0.05 level.*

TABLE (8) Post Hoc test comparing the XYZ deviations in the molar, incisors, canines, and premolar areas in group 1 (3d printing) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	.25208*	.01209	.000*
	canine	.26362*	.01561	.000*
	premolar	.22750*	.01209	.000*
incisor	molar	-.25208-*	.01209	.000*
	canine	.01153	.01710	1.000
	premolar	-.02458-	.01397	.507
canine	molar	-.26362-*	.01561	.000*
	incisor	-.01153-	.01710	1.000
	premolar	-.03612-	.01710	.238
premolar	molar	-.22750-*	.01209	.000*
	incisor	.02458	.01397	.507
	canine	.03612	.01710	.238

**. The mean difference is significant at the 0.05 level.*

TABLE (9) Post Hoc test comparing the X deviations in the molar, incisors, canines, and premolar areas in group 1 (3d printing) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	.16017*	.02934	.000**
	canine	.06583	.03787	.530
	premolar	.05917	.02934	.295
incisor	molar	-.16017-*	.02934	.000**
	canine	-.09433-	.04149	.164
	premolar	-.10100-*	.03387	.027
canine	molar	-.06583-	.03787	.530
	incisor	.09433	.04149	.164
	premolar	-.00667-	.04149	1.000
premolar	molar	-.05917-*	.02934	.295
	incisor	.10100*	.03387	.027*
	canine	.00667*	.04149	1.000

**. The mean difference is significant at the 0.05 level.*

TABLE (10) Post Hoc test comparing the Y deviations in the molar, incisors, canines, and premolar areas in group 1 (3d printing) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	.21000*	.01855	.000**
	canine	.34100	.02395	.000**
	premolar	.26175	.01855	.000**
incisor	molar	-.21000-*	.01855	.000**
	canine	.13100	.02624	.000**
	premolar	.05175	.02142	.116
canine	molar	-.34100-*	.02395	.000**
	incisor	-.13100-	.02624	.000**
	premolar	-.07925-	.02624	.024*
premolar	molar	-.26175-*	.01855	.000**
	incisor	-.05175-	.02142	.116
	canine	.07925	.02624	.024*

**. The mean difference is significant at the 0.05 level.*

TABLE (11) Post Hoc test comparing the Z deviations in the molar, incisors, canines, and premolar areas in group 1 (3d printing) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	-.04250-*	.01445	.030*
	canine	-.00750-	.01866	1.000
	premolar	-.00150-	.01445	1.000
incisor	molar	.04250*	.01445	.030*
	canine	.03500	.02044	.558
	premolar	.04100	.01669	.105
canine	molar	.00750*	.01866	1.000
	incisor	-.03500-*	.02044	.558
	premolar	.00600*	.02044	1.000
premolar	molar	.00150*	.01445	1.000
	incisor	-.04100-	.01669	.105
	canine	-.00600-	.02044	1.000

**. The mean difference is significant at the 0.05 level.*

TABLE (12) Comparison between deviations in the molar, incisors, canines, and premolar areas in group 2 (Milling) ANOVA test:

XYZ deviation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.811	3	.270	210.841	.000**
Within Groups	.064	50	.001		
Total	.875	53			
X deviation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	.266	3	.089	12.835	.000**
Within Groups	.345	50	.007		
Total	.611	53			
Y deviation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	.807	3	.269	56.715	.000**
Within Groups	.237	50	.005		
Total	1.044	53			
Z deviation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	.022	3	.007	4.448	.008**
Within Groups	.081	50	.002		
Total	.102	53			

**. The mean difference is significant at the 0.05 level.*

TABLE (13) Post Hoc test comparing the XYZ deviations in the molar, incisors, canines, and premolar areas in group 2 (milling) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	.24958*	.01266	.000**
	canine	.27250*	.01634	.000**
	premolar	.22750*	.01266	.000**
incisor	molar	-.24958-*	.01266	.000**
	canine	.02292	.01790	1.000
	premolar	-.02208-	.01462	.823
canine	molar	-.27250-*	.01634	.000**
	incisor	-.02292-	.01790	1.000
	premolar	-.04500-	.01790	.091
premolar	molar	-.22750-*	.01266	.000**
	incisor	.02208	.01462	.823
	canine	.04500	.01790	.091

**. The mean difference is significant at the 0.05 level.*

TABLE (14) Post Hoc test comparing the X deviations in the molar, incisors, canines, and premolar areas in group 2 (milling) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	.18208*	.02937	.000**
	canine	.06958	.03791	.435
	premolar	.05958	.02937	.287
incisor	molar	-.18208-*	.02937	.000**
	canine	-.11250-	.04153	.055
	premolar	-.12250-	.03391	.004**
canine	molar	-.06958-*	.03791	.435
	incisor	.11250	.04153	.055
	premolar	-.01000-	.04153	1.000
premolar	molar	-.05958-*	.02937	.287
	incisor	.12250*	.03391	.004**
	canine	.01000*	.04153	1.000

**. The mean difference is significant at the 0.05 level.*

TABLE (15) Post Hoc test comparing the Y deviations in the molar, incisors, canines, and premolar areas in group 2 (milling) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	.22917*	.02435	.000**
	canine	.25117	.03143	.000**
	premolar	.25817*	.02435	.000**
incisor	molar	-.22917-	.02435	.000**
	canine	.02200	.03443	1.000
	premolar	.02900	.02811	1.000
canine	molar	-.25117-*	.03143	.000**
	incisor	-.02200-*	.03443	1.000
	premolar	.00700*	.03443	1.000
premolar	molar	-.25817-*	.02435	.000**
	incisor	-.02900-	.02811	1.000
	canine	-.00700-	.03443	1.000

**. The mean difference is significant at the 0.05 level.*

TABLE (16) Post Hoc test comparing the Z deviations in the molar, incisors, canines, and premolar areas in group 2 (milling) Bonferroni test.

		Mean Difference	Std. Error	Sig.
molar	incisor	-.04233-*	.01419	.026*
	canine	-.00542-	.01832	1.000
	premolar	.01408	.01419	1.000
incisor	molar	.04233*	.01419	.026*
	canine	.03692	.02007	.431
	premolar	.05642	.01639	.007**
canine	molar	.00542*	.01832	1.000
	incisor	-.03692-	.02007	.431
	premolar	.01950	.02007	1.000
premolar	molar	-.01408-*	.01419	1.000
	incisor	-.02900-	.02811	1.000
	canine	-.00700-	.03443	1.000

**. The mean difference is significant at the 0.05 level.*

The sample of this study consisted of six models allocated into two groups; group I consisted of three models with a total of 52 attachments on the labial and buccal surfaces of the anterior and posterior teeth, respectively. Group II consisted of three milled models with 52 attachments on the anterior and posterior teeth' labial and buccal surfaces. The total number of attachments that were compared in this study was 104 **(Table 1).** The sample was further divided into four subgroups according to the tooth type as follows; incisors, 12 attachments in each group with a total of 24, canines six attachments in each group with a total of 12; premolars, 12 attachments in each group with a total of 24, and molars, 24 attachments in each group with a total of 48 **(Table 2).**

According to the tooth type comparison between the combined X, Y&Z deviation of the attachments to the original reference model was done by paired sample t-test, the results revealed a nonstatistical significant difference between both groups in all the directions of space **(Table 3).** Furthermore, comparing the two groups in the occlusogingival direction showed a nonstatistical significant difference between both groups and all subgroups **(table 4).** This finding was also observed when comparing both groups in mesiodistal and buccolingual directions **(Table 5&6).**

Intragroup comparison by one-way ANOVA test revealed a statistically significant difference among the deviations in both groups' molar, incisors, canines, and premolar areas, as shown in **tables 7& 12.** Bonferroni Post Hoc test was used to compare the mean deviations in the molar, incisors, canines, and premolar areas in group 1. In group 1, comparing the combined XYZ deviation revealed a statistically significant difference between molars and incisors, canines, and premolars deviations (*p-value* < 0.05); **table 8.** Comparing the deviations in the X plane revealed a statistically significant difference among the incisors, premolars, and molars (*p-value* < 0.05); **table 9**. The comparison in the Y plane showed statistically significant differences among molars, incisors, canines, and premolars (*p-value* <0.05); **table 10**. The Z-plane comparison revealed only a statistically significant difference between incisors and molars (*p-value* < 0.05); **table 11.**

In group 2, comparing the combined XYZ deviation revealed a statistically significant difference between molars and incisors, canines, and premolars deviations (*p-value* < 0.05); **table 13.** Likewise, comparing the deviations in the X plane revealed a statistically significant difference among the incisors, premolars, and molars (*p-value* <0.05); **table 14**. The comparison in the Y plane showed statistically significant differences among molars, incisors, canines, and premolars (*p-value* <0.05); **table 15**. The Z-plane comparison revealed only a statistically significant difference between incisors and molars (*p-value* < 0.05); **table 16.**

DISCUSSION

Aligner therapy has significantly changed from its inception in the 1970s. The mass-produced CAD/CAM aligner fabrication process transformed aligner treatment in the early 2000s. In the office, Clear aligners fabrication is a multi-step technique that involves obtaining a digital model either by direct intraoral scanning or desktop scanning, software planning, 3D model printing, and aligners fabrication (21). Composite attachments are essential to provide better control over several orthodontic tooth movements and better stability and retention of the aligners during function. The attachment shapes are variable according to the desired function needed (22). Rectangular attachments were used in this study on the anterior and posterior teeth as these attachments have a more pronounced line and point angles, facilitating points detection and further superimposition. The dimension of the rectangular attachments was standardized to allow better superimposition and minimize reading errors. Two rectangular attachments were added to the buccal surface of the molars, one for each cusp, to give a more accurate representation of the buccal surface of these teeth.

In this study, a priori sample size calculation was performed to help to achieve a power of 80%. This was important to decrease the probability of chance in this study. The sample size equation revealed that a sample of 3 models was needed in each group. Therefore, a total sample size of six models was selected, three models in each group. In order to ensure that the sample size was adequate after the trial was conducted, a post hoc power analysis was performed, and the power of the study was found to be 0.9933%.

Two main methods have been used for the prototyping of any object; additive 3D printing and subtractive milling. These technologies have expanded rapidly across different medical sectors, including dentistry(23). For additive manufacturing, two main methods are used for 3D printing; Stereolithography (SLA) and Fused Deposition Modeling (FDM). Both processes add material, layer by layer, to create objects. Although its being relative difficulty to use, the SLA printer type was found to be more accurate with higher quality and smoother surfaces of the printed objects. This is due to the higher resolution of the SLA printer, as its resolution was found to be more than double the resolution of FDM printers (24). So the 3D printer used in this study was an SLA printer. This printer is a low-budget printer that has sufficient Accuracy to be used for the orthodontic purpose (25). It also had a monochromic screen which was found to have a better resolution and a higher accuracy when compared to other LCD screens (26). 3D printing is dependent on several factors; the layer thickness and the light source type are the most prominent among all factors. Decreasing the layer thickness increases the surface quality and allows better curing of all the layers with a subsequent decrease in the post-processing curing time. This layer thickness allowed better precision of the 3D printed disc with subsequent improvement of the surface texture and good cohesion between the 3D printed disc layers to facilitate milling through it and decreas the chance of breakage (11). Thus the layer thickness used in this study is 0.05 mm.

In principle, milling shows a higher standardization and reproducibility as there is no influence by post-processing and light-curing as in the case of the printing resins. Still, the Accuracy can be influenced by different milling strategies, which is a limitation of our study. It should be noted that, in order to achieve maximum Accuracy, a time-consuming dual-milling procedure was selected for the benchmark technique of milling. Due to time constraints, a faster and less accurate setting is used during the standard application of the milling machine (17–20).

To the best of our knowledge, no previous studies have investigated how the Accuracy of 3D-printed dental models with attachments on the teeth compares with that of milled ones. Studies available in the literature compared between 3d printing milling technologies in the fabrication of complete dentures (17), zirconia crowns (18), peak materials (19), and inlay and onlay (20). This is important because all these studies compared different 3D printers and milling machines. The degree of clinically acceptable error was also variable between various studies due to the high variability of clinical application s(17–20).

No study has drawn firm and reliable conclusions as to whether the deviations between 3D-printed models and a reference model are clinically acceptable. It remains controversial whether differences in dimensions between the reference model and the 3D-printed models affect the accuracy of orthodontic appliances. Kasparova et al. compared traditional plaster casts, digital models, and 3D-printed models and found 3D-printed models to have advantages over traditional plaster casts due to their accuracy and price (10). Wan Hassan et al. compared the accuracy of measurements made on rapid prototyping and stone models with different degrees of crowding (8). They found significant differences for all planes in all categories of crowding except for crown height in the moderate crowding group and arch dimensions in the mild and moderate crowding groups. They concluded that the rapid prototyping models were not clinically comparable with conventional stone models.

The results of the current study revealed that the molars deviated in three ways of space greater than the incisors, canines, and premolars. This deviation was observed in both groups; 3D printing and Milling. The amount of deviation in group 1 was greater than in group 2. Comparing the means revealed a nonstatistical significant difference. These findings come in accordance with Dong et al.(7), who compared different surfaces of 3D printed models with the original STL files obtained from a direct intraoral scanner and found that the deviation in the molar segment was greater. Printing errors in the 3D-printed model can arise from each link of the printing process and the parameters thereof. These include residual polymerization of the resin, effects of support structures, print resolution (X and Y planes), layer thickness (Z plane), and surface finishing (27). This fact accounts for the greater significant difference observed in group 1 between all segments; molars, incisors, canines and premolars. In group two the relatively significant deviations found in this research may arise from the complexity of the surfaces and the high details created in each model during milling.

The results of this study revealed a non-statistically significant difference between 3D printed and milled dental models. These findings come in accordance with a multicenter analysis that compared milled and 3D-printed dentures in four centers with various printing and milling techniques. On the other hand, other studies which compared the two fabrication techniques in the manufacturing of zirconia crowns (18) and inlay and onlay (20) found that the milled objects had statistically higher trueness than 3D-printed ones. However, all crowns, inlays, and Onlays showed high precision, compatible with clinical use (18,20). This difference may be due to the heterogeneity of the data, the difference in measuring methods, the difference in sample size, and the outcome.

The potential errors may also be created by scanners and its procedures. Intraoral scanning and digital models are used widely in the clinic nowadays, such as Medit I600 used in this study. The precision and potential scan errors have been studied by many scholars. In a study (28) published in 2020 the authors compared between the accuracy of five different intraoral scanners and they reported a significant difference between scans obtained by different intraoral scanners, However, scans obtained by the same scanner were identical. So standardization of the scanner used in this study was done to minimize the potential errors.

The main disadvantage of the milling technique used in this study is the excessive material loss due to the fabrication of a resin disc and the milling of the model within it. 3D printing is more economical as it reduces the unnecessary loss of resin material with a subsequent decrease in the cost of the fabricated model. another advantage of 3D printing over milling is the time saving as the 3D printer can print more than one model in every cycle, on the other hand, the milling machine only manufactures one file in every cycle. So it is neither economic nor accurate to use milling to fabricate clear aligners models.

CONCLUSION

Based on the results of the current study the following conclusions were reported:

1. Regarding the accuracy; 3D printed models showed comparable results to the milled models.
2. 3D printing is more time and material saving
3. The average deviation of the posterior dentition was more obvious than that of the anterior region in both techniques.

RECOMMENDATION

Further investigation of the surface texture and smoothness of models created by both techniques and their effect on the surface texture and smoothness of the fabricated aligners should be further investigated.

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