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Original Article

Accuracy of 3D Printer Technologies Using Digital Dental Models

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Main Points

- No difference was observed between 3D printers in the dimensional tooth measurements.
- The mean root mean squared value in the stereolithography (SLA) group was presignificantly higher than that in the Digital Light Processing (DLP) and PolyJet groups.
- DLP and PolyJet printers produce more accurately than SLA technology.
- SLA, DLP, and PolyJet technologies are clinically appropriate for model production in the orthodontic field.

ABSTRACT

Objective: This study aimed to compare the manufacturing accuracy of different printing techniques - Stereolithography (SLA), Digital Light Processing (DLP), and PolyJet-using digital dental models.

Methods: The study included cast models of 30 patients aged between 12 and 20 years. The selected models were scanned using an intraoral scanner, and surface topography format files were obtained. The models were produced from 3D printers with SLA, DLP, and PolyJet technology and scanned with an intraoral scanner. The digital files of the reference and printed models were superimposed with reverse engineering software. Root mean squared (RMS) values and point registration differences were evaluated. Furthermore, digital mesiodistal measurements of the teeth were taken to determine the point registration deviation values. Descriptive statistics were used to evaluate the measurements. ANOVA was used to evaluate differences between normally distributed data. In addition, a box plot was used to show the variability in the measurements, and the Bland-Altman test was used to examine the agreement between the measurements.

Results: According to the digital superimposition data of DLP-SLA-PolyJet technologies, PolyJet had the smallest RMS (0.145±0.10 mm), followed by DLP and SLA (0.161±0.12 mm and 0.345±0.23 mm, respectively). In the mesiodistal dimensional measurement evaluations, there was no statistically significant difference ($p>0.05$) between the averages of the main reference and DLP, PolyJet, and SLA measurements for all teeth.

Conclusion: According to the results of this study, all three production technologies are clinically usable at the model production stage. However, SLA was found to be less accurate than DLP and PolyJet.

Keywords: 3-dimensional, 3-dimensional printing, digital dentistry, digital models

INTRODUCTION

In the field of dentistry, computer-aided design and computer-aided manufacturing (CAD/CAM) systems comprise three functional elements: data recording in the virtual environment, design preparation using software,

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and restoration production.[1] In recent years, 3D printing, also known as additive manufacturing, has emerged as a preferred technology. The process involves the deposition of successive layers of material to create a product, thereby representing a fundamental contrast to subtractive production technology.[2]

These systems are widely used in dental aligners, occlusal and surgical splints, indirect bonding trays, and surgical guides for mini screw placement in orthodontics.[3,4] The use of digital models is becoming increasingly prevalent due to the inherent disadvantages of plaster models, including rapid deterioration, difficulties in transfer, and the risk of cross-infection. The production of a physical dental model can be expedited by eliminating several steps in the traditional model-making process. Furthermore, the production of multiple copies without distortion is a more efficient process.[5]

Stereolithography (SLA) and Digital Light Processing (DLP) technologies are among the most widely used 3D printer technologies in dentistry due to their printing accuracy, speed, cost, and quality. In the SLA process, each layer is created by irradiating a photopolymerised ultraviolet (UV) laser along the object contour. After polymerization, the platform moves vertically according to the layer thickness, and the new layer is hardened by laser. This process is repeated to create a 3D product.[6] DLP technology is analogous to SLA technology in the polymerisation step, but the light source is distinct. DLP technology employs a high-resolution projector to simultaneously harden the entire layer. These technologies are frequently preferred in the field of orthodontics.[7] PolyJet technology employs a method of product creation that involves spraying hundreds of nozzle heads on a table surface with liquid resin. Then, curing with UV light is initiated immediately. Different materials can be sprayed with a large number of nozzles. A 16 µm layer thickness can be printed with high accuracy.[8] Another important difference between PolyJet and SLA and DLP printing techniques is that there is no post-production curing process. This technology is accepted as an accurate method but is more time-consuming and costly.[8]

In 3D printing, accuracy represents both accuracy and precision. The accuracy of a 3D-printed model may be affected by a number of factors throughout the manufacturing process, including model scanning, the design of the surface topography (STL) file, the production stage of the product, and post-production operations. The surface quality and accuracy of 3D printers are constrained by the thickness of the layers added successively along the z-axis, which gives rise to greater inaccuracies.[9]

Several studies have compared the accuracy of 3D printing technologies for dental use.[10-13] Baek et al.[10] compared SLA, DLP, and PolyJet technologies for the production of mandibular first molar teeth using different printer technologies. In addition, Camardella et al.[11] Manufactured dental models using different designs and compared SLA and Polyjet technologies. Salmi et al.[12] Compared the production efficiencies of SLS, 3DP, and PolyJet using 3D medical skulls. Emir and Ayyıldız[13] evaluated the accuracy of 3D printers by producing dental models designed using three different technologies. In light of the aforementioned data, this study aimed to compare the manufacturing accuracy of SLA, DLP, and PolyJet printing technologies using dental models obtained from different patients.

The null hypothesis of this study is that there is no difference in the production accuracy among SLA, DLP, and PolyJet technologies.

METHODS

The process is shown in the flowchart (Figure 1). The International Organization for Standardization (ISO) 5725-116 was used for the accuracy definition.[14] Ethical permission was obtained from University of Health Sciences Turkey, Gülhane Scientific Research Ethics Committee (approval no.: 2020-527: date: 29.112.2020) prior to study initiation.

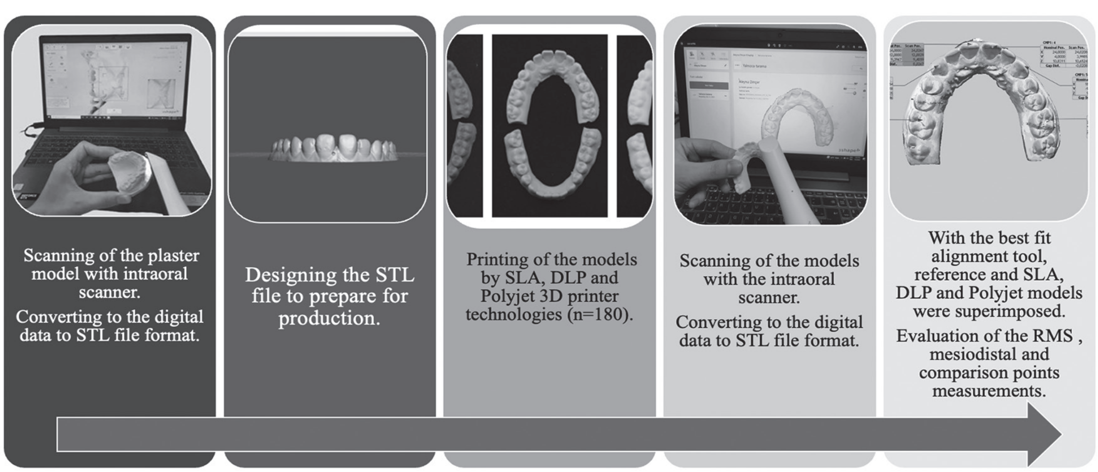

Figure 1. Flowchart of the study
SLA, stereolithography; DLP, Digital Light Processing; STL, surface topography; RMS, root mean squared

Sample Size Determination

Based on the power analysis obtained using G*Power 3.1.9.7 software, the effect size of the reference Emir and Ayyıldız[13] study was calculated as 0.425. At an effect level of 0.25 (effect size: 0.25), at least 159 samples are required for a 95% test power. Considering any potential error in the model production, a total of 180 patient models (30 maxillary and 30 mandibular models per group) from individuals aged 12-20 years between the ages of 12 and 20 were included in the study.

Inclusion Criteria

This retrospective study included the dental models of individuals with the following characteristics: no permanent tooth deficiencies, complete permanent dentition, no extensive restorations on teeth, to significant material loss due to caries or parafunctional habits, and crowding or a diastema between 0-4 mm.

Exclusion Criteria

The study excluded individuals in the deciduous and mixed dentition periods, those with excessive material loss or extensive restorations on teeth, individuals with crowding or diastema greater than 4 mm, models unsuitable for digital scanning from plaster models, and models for which proper scan data could not be obtained.

Study Design and Printing Process

Selected plaster models were scanned using the 3Shape Trios (Trios POD, 3Shape, Copenhagen, Denmark) intraoral scanner. STL files were designed in Autodesk Meshmixer software (version 3.5.474), and the digital files for 60 production-ready dental models were transferred to Formlabs PreForm 3.4.6 software from Formlabs™ Form 2™ (MIT Media Lab, Somerville, MA, USA). The STL files were positioned in parallel with the printer table, and two pairs of lower-upper models were present in each production run. The models were fabricated with a layer thickness of 0.100 mm using grey V4 resin (Formlabs™ Form 2™, MIT Media Lab, Somerville, MA, USA). The support structures of the fabricated models were separated by applying a manual force. The models were washed in a Form Wash tank for 20 min. They were then cured in a Form Cure tank at 60°C for 60 min.

The same digital files were transferred to an Asiga ® (Asiga, Sydney, Australia) 3D printer connected to Asiga Composer software using DLP technology. All models were placed horizontally on the machine with the occlusal plane parallel to the build platform and a pair of lower-upper models in each production. The printing layer thickness of the produced models was 50 µm. The raw material used was Dentamodel resin (Asiga, Sydney, Australia). The printed models were separated from the printing table. Support structures were then manually removed from the model. The uncured resin was cleaned in an ultrasonic bath with 99.8% isopropyl alcohol for 10 minutes. The models were polymerised for 10 minutes in the Asiga Flash ultraviolet polymerisation unit (Asiga, Sydney, Australia).

Additionally, the same digital files were transferred to GrabCAD Print 1.43 software connected to a (Stratasys J750, Eden Prairie, MN) 3D printer with PolyJet technology. STL files were placed parallel to the printer table, and multiple models were printed at once due to the large table. Verowhite resin (Stratasys, Eden Prairie, MN), which is matte and white, was used in the production. Waste material was removed from the model using a Powerblast 1.5-2 bar high-pressure cleaner. The printing process was shown in the flow chart (Figure 2).

Root Mean Square, Mesiodistal, and Comparison Point Measurements

The printed models were again scanned with a 3Shape Trios (Trios POD, 3Shape, Copenhagen, Denmark) intraoral scanner and digital files were created. When the model scans were completed, the reference and print model files were imported into Rapidform XOV/Verifier software (Rapidform, Inus Technology, S. Korea) for digital superimposition. The reference files were considered the control files, and the test files were considered the experimental files. Superimposition was performed using the best-fitting method, and the distances between the surface data and all points were converted to root mean square (RMS) values (Figure 3). RMS is a general method

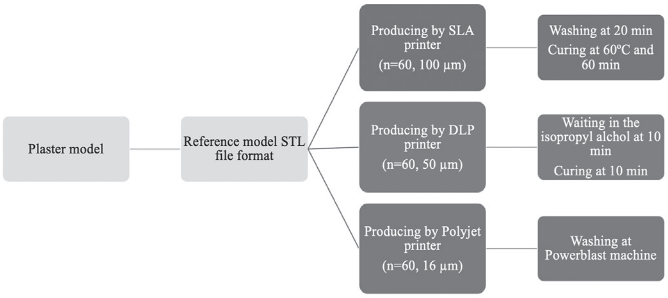

Figure 2. The process of 3D printing
SLA, stereolithography; DLP, Digital Light Processing; STL, surface topography

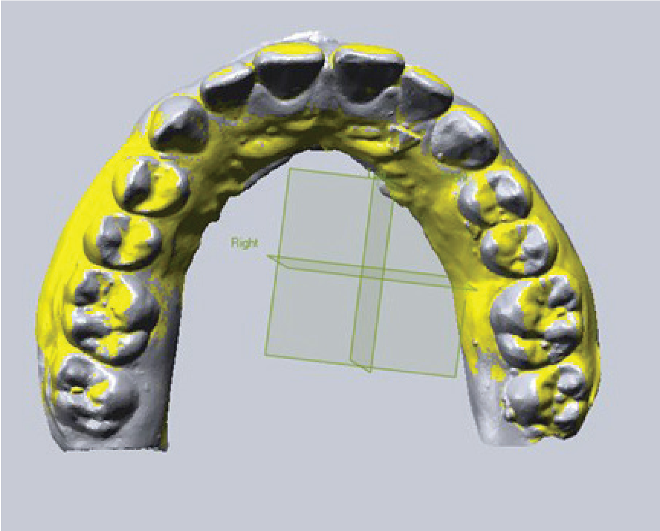

Figure 3. Best-fit alignment of reference and test models using reverse engineering software

to evaluate the mean error value by directly comparing two data groups with the same coordinate system. A higher RMS value indicates a large error between the reference and measurement data.

$$RMS = \frac{1}{\sqrt{n}}\sqrt{\sum_{i=1}^{n}\left(x_{1,i} - x_{2,i}\right)^2} \quad (1)$$

X1 in Equation (1) is the data point of reference i, X2 is the data point of experimental group i, and N is the number of all measurement points.

After superimposition, color surface maps were obtained for 3D comparison. The maximum critical value was ±0.25 mm, and the maximum nominal value for color spectra was ±0.025 mm. 0.25 mm is the threshold value of clinical admission for creating orthodontic movement. The maximum tooth movement per aligner ranged from 0.25 to 0.30 mm.[15] In the case of clear aligner therapy, dental models have an accuracy error below this value.[16]

After 3D comparison, the deviation values of the deepest point of the central fossa of the first molars, the cusps of the canines, and the midpoints of the incisal edges of the central incisors were used in the models for measurements (Figure 4). MeshLab software (v2022.02) was used to perform the dimensional measurements (Figure 5). The maximum distance measurements of the first molar, canine, and central incisors in the models from the occlusal surface between the mesial and distal contact points were made using the digital measurement tab in the software.

Statistical Analysis

The MedCalc version 20.113 (MedCalc Software Ltd, Acacialaan 22, Belgium) computer software was used for statistical analysis. In this study, ANOVA was used to evaluate whether there was a difference between the means of the main reference, DLP, PolyJet, and SLA measurements. In addition, two independent sample t-tests were used for pairwise comparisons between measurement techniques and group means. The BlandAltman and intraclass correlation coefficient (ICC) methods were used to evaluate the compatibility of the measurements obtained with the DLP, PolyJet, and SLA 3D printers with the main reference measurements. The paired t-test was used to determine whether there were statistically significant differences between the first and second measurements. The level of statistical significance was set as $p<0.05$. A box plot was used to visualize the visual distribution of variability in the RMS values.

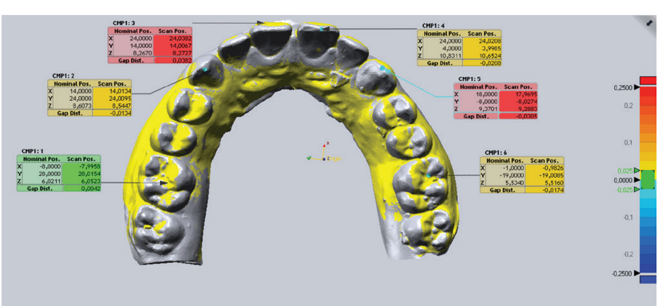

Figure 4. Comparison points of the printing models. **Point 1:** Deepest point of the central fossa of the right first molar, **Point 2:** Tubercle apex of the right canine tooth, **Point 3:** Midpoint of the incisal edge of the right central incisor, **Point 4:** Midpoint of the incisal edge of the left central incisor, **Point 5:** Tubercle apex of the left canine tooth, **Point 6:** Deepest point of the central fossa of the left first molar

RESULTS

Dimensional Measurement Results

Measurements were performed by a single researcher. The measurements of the models of five patients randomly selected from the groups were repeated two weeks apart by the same researcher using the same methodology and software. The ICC is a value between 0 and 1, where values below 0.5 indicate poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values above 0.9 indicate excellent reliability.[17] According to the ICC statistics of the present study, there was a perfect match between these 4 measurements for R1 and L1 teeth in the 95% confidence interval (0.964-0.961), and there was a good match between the measurements for R6, R3, L3 and L6 (0.849-0.887) teeth (Table 1).

According to the ANOVA test results for six different teeth, no statistically significant difference was observed between the means of the measurements made for six different teeth of the product obtained from the main reference and three different printers ($p>0.05$). In other words, there was no statistically significant difference between the mean of the main reference measurement values for all teeth and the mean of the

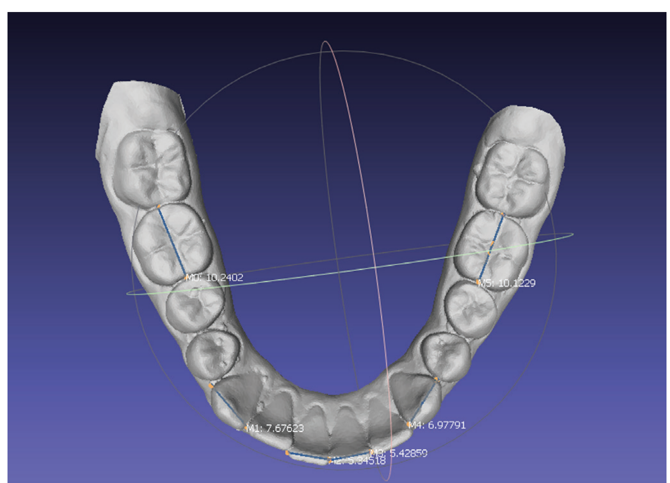

Figure 5. Mesodistal dimensional measurements. **R6:** Measurement of the distance between the mesial and distal contact points of the occlusal surface of the right 1st molar, **R3:** Distance between the mesial and distal contact points of the right canine tooth, **R1:** Distance between the mesial and distal contact points of the incisal edge of the right central tooth, **L1:** Distance between the mesial and distal contact points of the incisal edge of the left central tooth, **L3:** Distance between the mesial and distal contact points of the left canine tooth, **L6:** Distance between the mesial and distal contact points of the occlusal surface of the left 1st molar

measurements obtained using the DLP, PolyJet, and SLA printers ($p>0.05$). In comparing DLP, PolyJet, and SLA measurements for each tooth, no statistically significant difference was observed between the means of the measurements of these three printers ($p>0.05$) (Table 2).

For six teeth (R6, R3, R1, L1, L3, L6), a double independent sample-t test was used to determine whether there was a statistically significant difference between the means of the dimensional measurement values made in the software from the reference model and the models obtained from 3 printers. There was no statistically significant difference between the means of the groups in all binary combinations (Reference-SLA, Reference-DLP, Reference-PolyJet, SLA-DLP, SLA-PolyJet, DLP-PolyJet) that may occur between the means of the four measurements ($p>0.05$). Bland-Altman statistics were performed in the 95% confidence interval to examine the agreement between the main reference measurements and the measurements of three different printer models (SLA, DLP, and PolyJet). According to Bland-Altman statistics, the measurements obtained from three printers in the comparisons of six teeth were compatible with the main reference measurements.

Table 1. ICC statistical results for dimensional tooth measurements

Tooth	ICC value	(95% CI)
R6	0.887	(0.839,0.925)
R3	0.856	(0.796,0.903)
R1	0.964	(0.947,0.976)
L1	0.961	(0.942,0.974)
L3	0.849	(0.788,0.899)
L6	0.884	(0.835,0.923)

R6: Measurement of the distance between the mesial and distal contact points of the occlusal surface of the right 1st molar, R3: Distance between the mesial and distal contact points of the right canine tooth, R1: Distance between the mesial and distal contact points of the incisal edge of the right central tooth, L1: Distance between the mesial and distal contact points of the incisal edge of the left central tooth, L3: Distance between the mesial and distal contact points of the left canine tooth, L6: Distance between the mesial and distal contact points of the occlusal surface of the left 1st molar.
*There is a perfect agreement between these 4 measurements (0.964-0.961) for the R1 and L1 teeth at the 95% confidence interval, and a good agreement between the measurements for the R6, R3, L3 and L6 (0.849-0.887) teeth
ICC, interclass correlation coefficient; CI, confidence interval

RMS Value Results

When RMS values were examined according to DLP-SLA-PolyJet digital surface overlap data, the PolyJet printer had the lowest RMS value (0.145±0.10 mm). The DLP printer followed, with an RMS value of 0.161±0.12 mm. The SLA printer had the largest RMS value (0.345±0.23 mm). According to the ANOVA results, there was a statistically significant difference between the RMS means between at least two groups ($p<0.001$). According to the results of the Tukey Honestly Significant Difference (HSD) test, there was a statistically significant difference between the "SLA-DLP" and "SLA-PolyJet" RMS means ($p<0.001$). The mean RMS value of the SLA group (0.345±0.23 mm) was greater than that of the DLP group (0.161±0.12 mm), and this difference was statistically significant. Similarly, the mean RMS value of the SLA group was 0.345±0.23 mm, which was larger than the mean RMS value of the PolyJet group (0.145±0.10 mm) (Table 3). On the other hand, no statistically significant difference was observed between the means of the "DLP-PolyJet" groups ($p=0.999>0.05$). A box plot was used to visualize the visual distribution of variability in the RMS values (Figure 6).

3D Comparison Points with Superimposition Results

According to the results of the ANOVA test conducted to determine whether there was a difference between each group's means of DLP, PolyJet, and SLA measurements for 6 different teeth, a statistically significant difference was found inthe point comparison means of at least two groups for 6 different teeth ($p<0.001$). The Tukey HSD test for R6 and L6 teeth revealed statistically significant differences between the point measurement means of "SLA-DLP" and "SLA-PolyJet" ($p<0.001$). The SLA mean point comparison was higher than the DLP point comparison mean (0.169±0.234, 0.152±0.192) (0.52±0.675, 0.429±0.577), and these differences were statistically significant. Similarly, the mean SLA point comparison (0.52±0.675, 0.429±0.577) is greater than the PolyJet point comparison mean (0.121±0.147, 0.194±0.244), and these differences were also statistically significant. On the other hand, there was no statistically significant difference between the "DLP-PolyJet" point comparison means.

Table 2. ANOVA test results for reference, DLP, PolyJet, and SLA mesiodistal dimensional tooth measurements

Tooth	Reference	DLP	PolyJet	SLA	p-value
R6	10.506±0.641	10.463±0.676	10.582±0.733	10.497±0.706	0.813
R3	7.421±0.671	7.487±0.686	7.453±0.742	7.475±0.696	0.958
R1	7.138±1.704	7.154±1.724	7.104±1.707	7.117±1.716	0.999
L1	7.035±1.723	7.079±1.689	6.995±1.810	7.130±1.856	0.978
L3	7.322±0.722	7.396±0.704	7.323±0.689	7.479±0.637	0.552
L6	10.426±0.660	10.387±0.678	10.443±0.740	10.430±0.700	0.975

R6: Measurement of the distance between the mesial and distal contact points of the occlusal surface of the right 1st molar, R3: Distance between the mesial and distal contact points of the right canine tooth, R1: Distance between the mesial and distal contact points of the incisal edge of the right central tooth, L1: Distance between the mesial and distal contact points of the incisal edge of the left central tooth, L3: Distance between the mesial and distal contact points of the left canine tooth, L6: Distance between the mesial and distal contact points of the occlusal surface of the left 1st molar
*The statistical significance level was $p<0.05$
DLP, Digital Light Processing; SLA, stereolithography

According to the results of the Tukey HSD test for R3 and L3 teeth, there were statistically significant differences between the point-comparison means of "SLA-DLP" and "SLA-PolyJet" (p<0.001). The mean SLA point comparison was higher than the DLP point comparison mean (0.188±0.248, 0.188±0.231) and the PolyJet point comparison mean (0.158±0.191, 0.187±0.227), respectively (0.691±0.248, 0.688±0.231), and this size was statistically significant. On the other hand, no statistically significant difference was observed between the "DLP-PolyJet" point comparison means.

According to the results of the Tukey HSD test for R1 and L1 teeth, statistically significant differences were observed between the point-comparison means of "SLA-DLP" and "SLA-PolyJet" (p<0.001). The mean SLA point comparison was higher than the DLP point comparison mean (0.217±0.270, 0.212±0.263) and the PolyJet point comparison mean (0.199±0.208, 0.198±0.233), respectively (0.638±0.553, 0.639±0.537), and this size was statistically significant. Conversely, no statistically significant difference was found between the "DLP-PolyJet" point comparison means (Table 3).

DISCUSSION

In the present study, it was compared whether there is a difference between the manufacturing accuracy of dental models produced using SLA, DLP, and PolyJet 3D printer technologies. The best-fit algorithm method was employed in the reverse engineering software to evaluate the accuracy of the printed models in comparison with the reference models. The best-fit algorithm method was selected in instances where the mean deviation between the reference model and the measurement data was minimal. Previous studies have investigated dimensional accuracy and presented their findings in absolute measurements in millimeters or dimensional ratios in percentage.[18-20] However, it should be noted that deviations can occur, both in a positive and negative direction, from the reference model. The RMS value defines the deviation from this mean value as the mean of the squares of all data. Therefore, this study focused on the preferred RMS value in recent studies.[10-13]

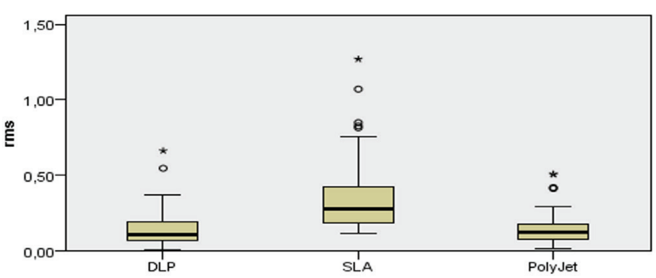

Figure 6. Comparison of total RMS values of the DLP, SLA, and PolyJet printing technologies
SLA, stereolithography; DLP, Digital Light Processing

According to the results of our study, DLP-SLA-PolyJet technologies showed that Polyjet technology had the lowest RMS mean according to RMS data (0.145±0.10 mm), followed by DLP and SLA technologies (0.161±0.12 mm and 0.345±0.23 mm, respectively). Kim et al.[9] compared the accuracy of different printing technologies using dental models in a recent study and stated that the PolyJet technique showed the highest accuracy with an RMS value of 0.78 mm, followed by SLA, DLP, and fused filament fabrication technologies (0.107, 0.143 and 0.188, respectively). The layer thickness was produced for each printer technology at the most accurate settings. The authors reported that the thinnest layer thickness used in PolyJet technology positively affected accuracy.[21-23] In this study, PolyJet showed the thinnest layer thickness and gave the most accurate results. Post-production curing in SLA and DLP techniques produced using the photopolymerization method may affect the dimensional accuracy of the products.

Yoo et al.[24] compared the accuracy of producing a 3-unit fixed prosthesis model using SLA, DLP, and MJP printing technologies similar to our study. The authors concluded that the MJP models revealed greater accuracy than those produced using DLP and SLA technologies. No significant differences were observed in terms of precision, and the three technologies were considered suitable for dental model production. These findings are in accordance with the results of our study.

Table 3. Descriptive statistics of the comparison points and RMS values

	DLP				SLA				PolyJet				
Tooth	Mean±SD	Min.	Max.	Median	Mean±SD	Min.	Max.	Median	Mean±SD	Min.	Max.	Median	p-value
R6	0.169±0.234[a]	0	1.48	0.069	0.520±0.675[b]	0	3.63	0.271	0.121±0.147[a]	0	0.6	0.066	**<0.001***
R3	0.188±0.248[a]	0	0.98	0.081	0.691±0.561[b]	0.06	2.38	0.523	0.158±0.191[a]	0	0.82	0.097	**<0.001***
R1	0.217±0.270[a]	0	1.14	0.090	0.638±0.553[b]	0	2.32	0.549	0.199±0.208[a]	0	0.89	0.141	**<0.001***
L1	0.212±0.263[a]	0	1.16	0.100	0.639±0.537[b]	0.01	2.44	0.479	0.198±0.233[a]	0	0.92	0.095	**<0.001***
L3	0.188±0.231[a]	0	0.86	0.075	0.688±0.619[b]	0.01	2.43	0.498	0.187±0.227[a]	0	0.99	0.103	**<0.001***
L6	0.152±0.192[a]	0	1.16	0.100	0.429±0.577[b]	0	3.36	0.25	0.194±0.244[a]	0	0.93	0.088	**<0.001***
RMS	0.161±0124[a]	0	0.66	0.107	0.345±0.237[b]	0.11	1.27	0.273	0.145±0.103[a]	0.01	0.51	0.120	**<0.001***

R6: Deepest point of the central fossa of the right first molar, R3: Tubercle apex of the right canine tooth, R1: Midpoint of the incisal edge of the right central incisor, L1: Midpoint of the incisal edge of the left central incisor, L3: Tubercle apex of the left canine tooth, L6: Deepest point of the central fossa of the left first molar
*The statistical significance level was p<0.05; Groups with different letters are significantly different from each other
RMS, root mean square; SD, standard deviation; Min., minimum; Max., maximum; DLP, Digital Light Processing; SLA, stereolithography

Camardella et al.[11] conducted a comparative analysis of the accuracy of dental models produced with different model base designs using SLA and PolyJet technologies. The results showed that the models printed with the PolyJet printer were more accurate in all designs, independent of the design of the model base. Additionally, the authors also attributed the higher RMS values of SLA technology to the higher post-polymerization shrinkage in SLA. In this study, SLA produced the least accuracy compared to other technologies, supporting the study of Camardella et al.[11]

Zhang et al.[21] investigated the impact of model accuracy on different printing technologies. A comparison was conducted between models produced using SLA and DLP technologies with a layer thickness of 100 µm, which revealed that DLP technology demonstrated superior performance in terms of speed and accuracy compared to SLA.

Salmi et al.[12] conducted a study comparing 3D medical skull models produced using selective laser sintering (SLS), 3DP, and PolyJet technologies and concluded that the size error of the PolyJet model was 0.18±0.12 µm, the error of the SLS model was 0.79±0.26 µm, and that of the 3DP model, it was 0.67±0.43 µm. The models produced with a PolyJet printer had the lowest size error and showed higher accuracy than those produced with 3DP and SLS. The authors stated that differences in accuracy might be due to the imaging, segmentation, and production stages. The fact that PolyJet, which showed the highest accuracy in this study, gives more accurate results than other technologies can be associated with the fact that the curing process is in production.

In their study on the effect of the additive manufacturing process and storage conditions on the dimensional accuracy and stability of 3D-printed dental models, Yousef et al.[25] found that the RMS value of models produced from a DLP 3D printer had a significantly higher average than those produced with a MultiJet 3D printer. These findings support our conclusion that Multijet technology provides more accurate results.

Baek et al.[10] reported that SLA models showed higher accuracy than DLP and PolyJet models in studies that printed mandibular first molars using SLA, DLP, and PolyJet technologies ($p<0.05$). This difference in the results was due to the following reasons: curing of the model during the production stages, the conditions after polymerization, the dimensional smallness of the produced object, and the thickness of the thin layer. The degree of post-production resin shrinkage is contingent upon the dimensional levelling and the modelling material employed, and may potentially impact the accuracy of the manufactured models. In their study, Emir and Ayyıldız[13] reported mean RMS values of 51 µm for SLA, 46 µm for DLP, and 58 µm for PolyJet. Despite the layer thickness (16 µm) of the PolyJet printer being less than that of the DLP printer (50 µm), the DLP models demonstrated superior accuracy compared to the PolyJet models. It was concluded that high-resolution printers could produce models with minute details, but that the accuracy of the printed materials could be affected. The raw material scale used in PolyJet printing technology is diverse and consists of various colors, transparencies, and hardness values. Emir and Ayyıldız[13] employed transparent and bright resin in PolyJet printing technology; since this product is transparent, a thin-layer scanning spray was applied to the PolyJet models to scan the surface. The deviations observed in the PolyJet models may be due to the thickness of the screening spray. In the present study, matte and white resin were selected for two reasons: firstly, high-resolution models could be produced, and secondly, no additional processing was required for scanning due to the matte surface. Therefore, PolyJet manufactures detailed products with high accuracy.

Study Limitations

According to the literature, 0.20-0.50 mm is considered as an acceptable range for clinical accuracy in dental models.[26,27] This study evaluated the RMS values of the SLA, DLP, and PolyJet technologies, concludng that three are suitable for clinical use. In addition, clinicians can choose the technology based on the aim, quantity, and size of the model, working time, and cost. Future, more comprehensive studies could use improved and updated versions of the same devices. Further optimization of these technologies may focus on the following aspects: clinical efficiency with less raw material, low cost, high performance, and production speed.

Conclusion

Root mean square values indicated that the mean value in the SLA group was noticeably higher compared to the DLP and PolyJet groups, while the DLP and PolyJet groups exhibited comparable mean values.

• The SLA, DLP, and PolyJet production technologies used in this study are clinically available for model production in terms of orthodontics. However, DLP and PolyJet printers produce more accurately than SLA technology.

Ethics

Ethics Committee Approval: Ethical permission was obtained from University of Health Sciences, Gülhane Scientific Research Ethics Committee (approval no. 2020-527: date: 29.112.2020) before the study initiation.

Informed Consent: This retrospective study was conducted using plaster models obtained from patients at the University of Health Sciences Turkey, Gülhane Faculty of Dentistry, Department of Orthodontics.

Footnotes

Author Contributions: Surgical and Medical Practices - Ş.G., G.S.D.; Concept - Ş.G., S.G., G.S.D.; Design - Ş.G., S.G., K.G.T., G.S.D.; Data Collection and/or Processing - Ş.G., S.G., K.G.T.; Analysis and/or Interpretation - Ş.G., K.G.T., G.S.D.; Literature Search - Ş.G.; Writing - Ş.G.

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

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