

Evaluating the accuracy between hollow and solid dental aligner models: a comparative study of printing technologies

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Objective: To evaluate the accuracy between hollow and solid dental models produced using a Stereolithography Apparatus (SLA), Digital Light Processing (DLP), and PolyJet 3D printing technologies.

Materials and methods: Hollow (of 1 mm, 2 mm, 3 mm shell thicknesses) and solid maxillary models were produced using SLA, DLP, and PolyJet printers. To determine the accuracy of the tested models and deviations from the reference models, 3D digital superimposition was performed. For a detailed analysis, the dental arch was subdivided into five regions which yielded root mean square (RMS) values post-registration. Six different RMS values were generated, one for the total dental arch and one for each of the five individual regions. One-Way ANOVA analysis was applied for intergroup comparisons, and post hoc comparisons were conducted using the Tukey test. The significance of the deviation of RMS values from zero was evaluated through the one-sample *t* test.

Results: The PolyJet printer produced models with the least deviation for the total arch, while the SLA printer showed the greatest deviation. The DLP printer produced models with the least deviation for the hollow designs in the anterior region, while the SLA printer produced models with the least deviation of the solid design. The PolyJet printer showed the least deviation for both hollow and solid designs of 2 mm and 3 mm shell thicknesses in the molar regions. Except for the 1 mm shell thickness hollow design on the right side, the PolyJet printer showed the highest accuracy in the premolar-canine regions.

Conclusion: Accuracy varies in the posterior and anterior regions of the dental arch as a result of different shell thicknesses produced by 3D printing technologies. The clinician should select a design that is appropriate for the intended 3D printing technology based on use and required accuracy.

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Introduction

The integration of innovative developments in digital technology into dental practice has enabled clinicians to create customised treatment tools and offer personalised treatment options to patients.¹ A prominent example of these advancements is the production of orthodontic diagnostic and study

models using three-dimensional (3D) printing technologies.^{2,3} 3D printing is widely utilised in orthodontics to produce metal or acrylic appliances, occlusal splints, and surgical guides for mini-screw placement.^{4,5} The application of these systems has significantly reduced the problems encountered during traditional impression and plaster model

production.⁶ 3D printing is also widely employed in the production of clear aligners, which have become a highly popular treatment option. In the early years of clear aligner therapy, material supply was limited. However, with the decrease in cost and increased accessibility of 3D printing equipment, clinics and laboratories have developed in-house manufacturing systems.^{7,8} It is emphasised that the high accuracy of production of aligner models containing precise attachments is critical for the successful progression of patient treatment.^{9,10}

The in-house development of clear aligner production systems enables clinicians to have complete control over the treatment plan and efficiently implement changes to the aligners. Within these systems, intermediate steps such as contacting the company for treatment stage planning and obtaining new aligners are eliminated. Unlike systems that rely on aligners provided by companies, there is no additional shipping cost nor time required for new aligners. This allows for faster and more cost-effective patient treatment.¹¹ Photocuring-based systems using resin of different properties have become a significant preference in the production of clear aligners. Models can be produced with high precision using desktop equipment options like StereoLithography Apparatus (SLA) and Digital Light Processing (DLP) technologies.^{12,13} PolyJet, a printing method utilising material jetting technology, is capable of producing high-capacity prints with precision up to 14 µm.¹⁴ Although accessibility to printing equipment has increased, the cost can still remain high in clinics with a high patient turn-over. A system's cost-intensive stage is the production of base models used for thermoforming each aligner. Prior to model production, reducing the cost, time, and laboratory stages may be achieved by making changes in the internal structure and design of the base models.¹⁵ Models produced through 3D printing can be manufactured in a solid state similar to plaster models or in a hollow structure that requires less resin and incurs lower costs.¹⁶ The reduced resin quantity necessary for hollow model production also results in a decrease in the amount of waste which benefits the environment.

Recently, studies have evaluated the accuracy of hollow model designs that require less resin compared to solid models. Rungrojwittayakul et al. examined the accuracy of solid and hollow models produced

with a 2 mm wall (shell) thickness using Continuous Liquid Interface Production (CLIP) and Digital Light Processing (DLP) techniques.¹⁷ Chanyawatana et al. evaluated the accuracy of hollow and solid models of 11 different base designs produced using Liquid Crystal Display (LCD) technology through a 3D surface matching method.¹⁶ Ultimately, both studies indicated that the hollow models, which were produced at a lower cost, demonstrated sufficient accuracy for clinical use.^{16,17} Leon et al. evaluated the effect of solid, honeycomb, and hollow base designs on the accuracy of maxillary models. It was noted that honeycomb cast bases, which reduced material and manufacturing time, exhibited high accuracy.¹⁸ Kenning et al. evaluated the dimensional accuracy of five different shell thickness hollow designs and solid designs produced using a SLA printer during the thermoforming process and recommended a minimum shell thickness of 2.0 mm for clinical utility.¹⁹ Model designs produced by 3D manufacturing methods have been assessed and have revealed that the accuracy of the design is dependent on the production technology and the type of 3D printer utilised by the clinician.

While the use of hollow models allows for a reduction in production cost and time, dimensional changes may occur due to the decreased thickness of the internal structure during printing and lead to misdiagnosis and appliance production errors.¹⁵ Therefore, it is necessary to identify a model design that allows for optimal modelling of the dental arches while requiring less resin in production. The aim of the present study was to evaluate the accuracy of hollow models printed with 1 mm, 2 mm, and 3 mm shell thicknesses against solid models produced using SLA, DLP, and PolyJet printing technologies.

Materials and methods

Model accuracy was defined in accordance with the International Organisation for Standardisation (ISO). According to the applied methodology, higher accuracy indicates that a 3D printer can produce an object that closely matches or is identical to a reference digital object.^{20–22}

Digital design of the control models

The study's workflow is illustrated in Figure 1. Initially, a typodont maxillary model (Sino Dental

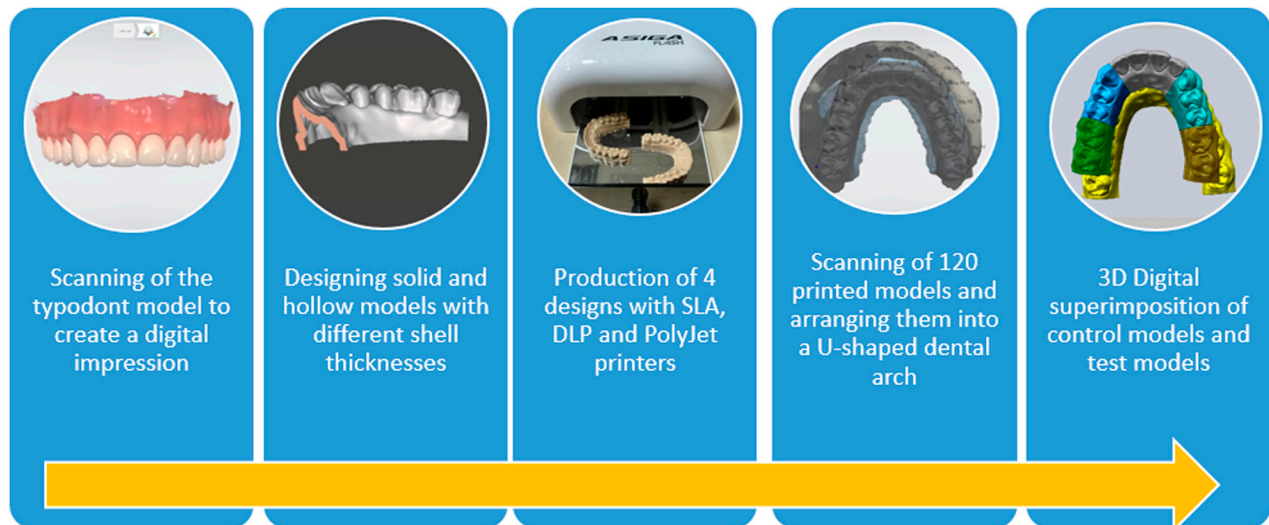


Figure 1. The flow chart of the study.

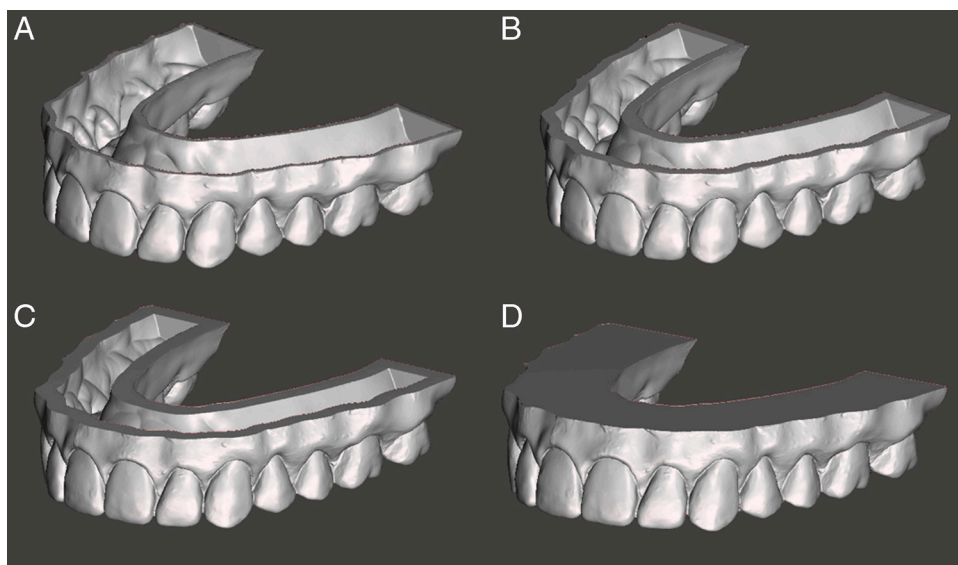


Figure 2. Hollow designs with (A) 1 mm, (B) 2 mm, (C) 3 mm shell thickness and (D) Solid design.

Typodonts Dental Training Models, China) was scanned using an intraoral scanner (3Shape TRIOS, Copenhagen, Denmark) to create a digital impression which included teeth and gingival tissues. The digital scan was saved in an appropriate standard tessellation language (STL) file format and transferred into 3D modelling software (Meshmixer version 3.5; Autodesk, San Rafael, CA, USA). Unnecessary structures were removed, and a U-shaped dental arch was created. Based on this arch, four different designs were produced, including solid and hollow models

with shell thicknesses of 1 mm, 2 mm, and 3 mm (Figure 2).

Determining the Sample Size

G*Power software version 3.1 (Heinrich Heine Universität, Düsseldorf, Germany) was utilised to determine the number of models required for the four different designs. Previous similar studies were taken into consideration, and a minimum within-group sample size of 10 was determined at an effect size of

0.56 for a test power of 80%.^{16,17} Chanyawatana et al. evaluated 10 different hollow and solid model designs and produced 10 samples for each group using an LCD printer.¹⁶ Similarly, Rungrojwittayakul et al. evaluated two model designs using two different printing technologies and produced 10 samples for each group.¹⁷ A total of 40 samples were required for three different hollow, and solid design groups, with 10 models for each design. Therefore, using SLA, DLP and Polyjet printers, a total of 120 models were produced for evaluation.

Production of test models and generation of digital measurements

Production using DLP technology

The ASIGA MAX UV printer (Asiga, Sydney, Australia) was used for the production of the test designs using DLP technology. To plan the production stages, the designs were transferred to the printer interface software (ASIGA Composer, version 1.2.11, Sydney, Australia). Two models were placed on the simulated printer bed, with the occlusal surfaces facing the resin tank at a 45° angle. The layer thickness for printing was set at 50µm.²³ Dental model resin (Asiga DentaMODEL, Sydney, Australia) was used in accordance with the manufacturer's recommendations. After completion of the production process, the support structures were removed from the models, which were then placed in an ultrasonic cleaner containing a 99.8% isopropyl alcohol solution until all residual material was removed.²⁴ Subsequently, a 10-min post-curing process was performed using a UV light chamber unit (Asiga Flash Curing Unit, Sydney, Australia).

Production using PolyJet technology

A Stratasys J750 printer (Stratasys Ltd., Rehovot, Israel) was used for the production of the test designs using PolyJet technology. The designs were transferred to the printer interface software (GrabCAD Print, version 1.69, Stratasys Ltd., Rehovot, Israel) to adjust the production settings. The models were positioned on the production tray at a 45° angle and a layer thickness of 14µm was selected for printing.²⁵ The VeroPureWhite resin (Stratasys Ltd., Rehovot, Israel) was used for the production of the test models, and the FullCure705 resin (Stratasys Ltd., Rehovot, Israel) was used for the production of support structures.

After completion of the production process, a high-pressure water jet cleaning unit (Balco Powerblast High Pressure Water Cleaning Cabinet, Rehovot, Israel) was used to remove the support structures from the models.

Production using SLA technology

Production of the test designs using SLA technology was carried out using the Form 3L printer (Formlabs, Somerville, MA, USA). The models were positioned on the simulated production tray in the printer interface software (PreForm version 3.28.0, Formlabs, Somerville, MA, USA) with the occlusal surfaces facing the resin tank at a 45° angle. A layer thickness of 100 µm was set for printing.^{26,27} Grey Resin (Formlabs, Somerville, MA, USA) was used for the printing process. The produced models were placed in an ultrasonic cleaner filled with a solution containing 90% isopropyl alcohol (Form Wash; Formlabs, Somerville, MA, USA) according to the manufacturer's recommendations for 20 min until residual material was removed.²⁸ Subsequently, for enhanced stability, the models were cured at 60°C for 60 min (Form Cure; Formlabs, Somerville, MA, USA).

A total of 120 models produced by the three different printers were scanned and saved in an appropriate file format. The digital measurements were arranged into a U-shaped dental arch form, similar to the reference models, using the same modelling software.

3D Digital Superimposition of control models and test models

To determine the accuracy of the tested models and the deviations from the reference models, 3D digital superimposition was performed using reverse engineering software (Rapidform XO/Verifier, Rapidform, Inus Technology). For a detailed analysis, the dental arch was divided into five regions (Figure 3). The reference model and the test model were aligned using the 'initial alignment' and 'best fit' tools, and surface deviations were visualised (Figure 4). The root mean square (RMS) value was applied to quantify the deviations between the two groups. As a result, six different RMS values were obtained, one for the overall dental arch and one for each of the five individual regions.

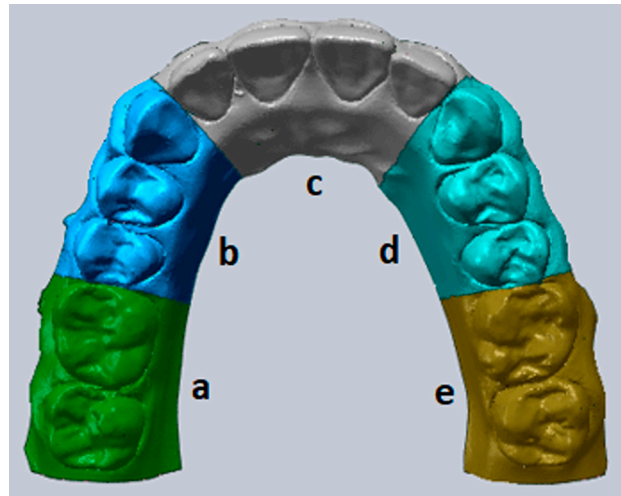


Figure 3. Dividing of the reference model into 5 different regions. (a) Molar Region (Right): right first and second molar teeth, palatal and buccal gingival area. (b) Canine-Premolars Region (Right): right canine and premolar teeth, palatal and buccal gingival area. (c) Anterior Region: right and left central and lateral teeth, palatal and buccal gingival area. (d) Canine-Premolar Region (Left): left canine and premolar teeth, palatal and buccal gingival area. (e) Molar Region (Left): left first and second molar teeth, palatal and buccal gingival area.

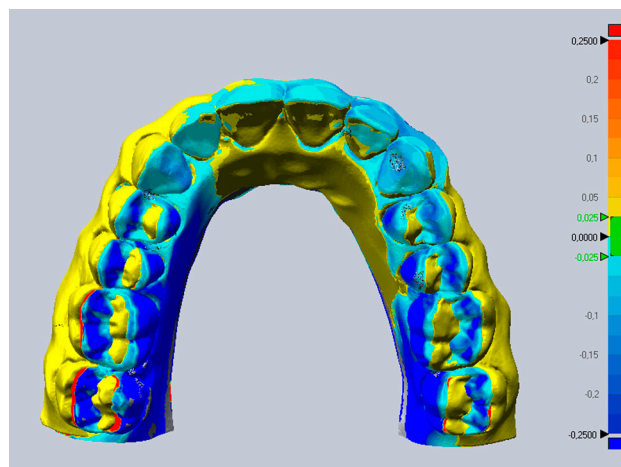


Figure 4. Superimposition of reference and test model.

Statistical analyses

Descriptive statistics, including mean and standard deviation values, were provided for the measurement data. The Shapiro–Wilk test was used to assess the normality of the data distribution within each group. As a normal distribution was observed in the groups, intergroup comparisons were conducted using one-way ANOVA. Post-hoc analyses were performed using the Tukey test. The significance of the deviation of RMS values from zero was evaluated through a one-sample t-test.

A threshold value of 0.25 mm was determined to be clinically acceptable for model production,

as previous studies have indicated that a 0.3 mm deviation is satisfactory for the reconstruction of orthodontic dental casts and the tooth movement provided by each aligner in clear aligner treatment is typically within the range of 0.25 to 0.3 mm.^{29,30} The amount of resin to be consumed by each printer for the different designs was provided by the printer interface software. The amount of resin that would be saved by using hollow designs instead of solid models was calculated as a percentage. SPSS software (Version 26, IBM Corp., Armonk, NY, USA) was used for all statistical analyses, and $p < 0.05$ was considered statistically significant.

Table I. Comparisons of Total Arch RMS values

Designs	DLP ¹	Polyjet ²	SLA ³	<i>p</i> ¹	Posthoc ¹
	Mean ± SD	Mean ± SD	Mean ± SD		
1 mm ^A (n = 10)	0.36 ± 0.14	0.29 ± 0.13	0.57 ± 0.15	0.001	2-3*
2 mm ^B (n = 10)	0.26 ± 0.04	0.18 ± 0.07	0.34 ± 0.06	0.002	1-2* 1-3* 2-3*
3 mm ^C (n = 10)	0.21 ± 0.04	0.13 ± 0.06	0.24 ± 0.05	<0.001	1-2*** 2-3**
Solid ^D (n=10)	0.09 ± 0.01	0.08 ± 0.03	0.14 ± 0.01	<0.001	1-3*** 2-3*
<i>p</i> ²	<0.001	<0.001	<0.001		
Posthoc ²	A-B*, A-C***	A-B*, A-C***	A-B***		
	A-D***	A-D***	A-C***		
	B-D***	B-D *	A-D***		
	C-D***		B-D***		

p* < 0.05, *p* < 0.01, ****p* < 0.001.

*p*¹, Repeated measures ANOVA; *p*², One-way Anova Analysis; Post Hoc¹, Bonferroni Correction; Posthoc², Tukey's Test; SD, Standart Deviation.

Results

In the comparisons of the Total Arch, the models produced by the PolyJet printer demonstrated the highest accuracy for all designs, while models produced by the SLA printer showed the lowest accuracy (Table I). PolyJet technology exhibited statistically higher accuracy than the SLA printer for a 1 mm shell thickness and solid models, and was more accurate than both the SLA and DLP printers for the 2 mm and 3 mm shell thicknesses (*p* < 0.001, *p* < 0.01, *p* < 0.05).

For the measurements in the Anterior Region, the DLP system had the lowest variation for 1 mm and 2 mm thickness models (0.08 ± 0.04; 0.06 ± 0.01, respectively), while the SLA printer showed the highest variation (0.12 ± 0.03; 0.09 ± 0.02, respectively) (Table II). For the 3 mm shell thickness, the deviations observed in the DLP and PolyJet printers were lower than those for the SLA printer. The highest accuracy in the solid models was created by the SLA printer, followed by the DLP and PolyJet printer systems (0.04 < 0.01; 0.05 ± 0.01; 0.06 ± 0.01, respectively).

In the Canine-Premolar Region (right), no significant difference was observed between the printers for the 1 mm shell thickness designs (*p* > 0.05) (Table III). For 2 mm and 3 mm shell thickness models, the PolyJet printer showed the lowest variation (0.06 ± 0.01; 0.05 ± 0.01, respectively), while the SLA printer exhibited the highest variation (0.14 ± 0.06;

0.10 ± 0.01, respectively). In comparison to other designs, the PolyJet printer showed lower accuracy for the 1 mm shell thickness, while solid designs from the DLP and SLA printers exhibited significantly higher accuracy. According to the RMS value averages for the Canine-Premolar Region (left), the PolyJet showed the lowest deviation of all printers. The highest deviation was observed in DLP for the 2 mm, 3 mm, and the solid designs, while the SLA printer showed the highest deviation for the 1 mm shell thickness.

In the Molar Region (right), the DLP printer exhibited the lowest deviation for the 1 mm shell thickness designs (0.17 ± 0.02), while the PolyJet printer showed the lowest deviation for the other designs (Table IV). For the hollow designs, the highest deviation was observed using the DLP printer (0.13 ± 0.02), while for the other designs, the SLA printer showed the greatest variation. The hollow design produced by the PolyJet printer, with a shell thickness of 1 mm (0.36 ± 0.26) showed statistically higher deviation compared to the other designs, while using the SLA printer produced less deviation in the solid design (0.12 ± 0.01). In the Molar Region (left), the PolyJet printer showed statistically higher accuracy in all designs compared to the other printers (*p* < 0.001, *p* < 0.01). The SLA exhibited lower accuracy for 3 mm shell thickness and the solid designs.

In the majority of the hollow designs, the deviation level remained below the clinically significant

Table II. Comparisons of Anterior Region RMS values

	DLP ¹	PolyJet ²	SLA ³		
Designs	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	p^1	Post-hoc ¹
1 mm ^A (n = 10)	0.08 $\pm$ 0.04	0.10 $\pm$ 0.02	0.12 $\pm$ 0.03	0.040	>0.05
2 mm ^B (n = 10)	0.06 $\pm$ 0.01	0.07 $\pm$ 0.01	0.09 $\pm$ 0.02	<0.001	1-3*** 2-3*
3 mm ^C (n = 10)	0.06 $\pm$ <0.01	0.06 $\pm$ 0.01	0.07 $\pm$ 0.01	0.002	1-2** 1-3** 2-3**
Solid ^D (n = 10)	0.05 $\pm$ 0.01	0.06 $\pm$ 0.01	0.04 $\pm$ <0.01	<0.001	1-2** 1-3** 2-3**
p^2	0.003	<0.001	0.001		
Post-hoc ²	A-D**	A-B***, A-C*** A-D***	A-B**, A-C*** A-D***, B-C* B-D***, C-D**		

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

p^1 , Repeated measures ANOVA; p^2 , One-way Anova Analysis; Post Hoc¹, Bonferroni Correction; Post-hoc², Tukey's Test; SD, Standard Deviation.

tolerance limit of ± 0.025 mm. For the total arch, the deviations in hollow design with a 2 mm shell thickness produced by the PolyJet printer and the hollow design of a 3 mm shell thickness model produced using the DLP and SLA printers did not exceed the clinically significant tolerance limits. In the anterior region, the hollow design with a 1 mm shell thickness produced by the three printers exhibited accuracy within clinically acceptable tolerance limits. In the molar region, the hollow models with a 2 mm shell thickness produced using the PolyJet printer exhibited acceptable tolerance limits. In the canine-premolar region, the hollow models with a 1 mm shell thickness produced by the PolyJet printer and the hollow design with a 2 mm shell thickness produced using the DLP and SLA printers demonstrated deviations that did not exceed the clinically acceptable tolerance limits. The amount of resin that would be saved by using the hollow designs instead of solid models by the different printers is indicated in Table V.

Discussion

The objective of the present study was to assess the accuracy of solid and hollow designs for the economical production of aligner models using SLA, DLP, and PolyJet printing technologies in in-house systems. Hollow models with varying shell thicknesses in different regions of the dental arch demonstrated sufficient accuracy. Instead of solid designs, it was observed that hollow designs with a

2 mm shell thickness using a PolyJet printer, and a 3 mm shell thickness using DLP and SLA printers, could be used for model production with clinically acceptable accuracy.

Factors specific to 3D printing technologies, such as layer thickness, curing conditions, resin type, and printer specifications, affect the accuracy of models produced by photopolymer-based 3D printing systems.^{12,31–34} A literature review noted that studies investigating the additional effect of various technologies on production accuracy mostly utilised 3D digital superimposition and considered the entire dental arch. Park et al. studied mandibular models produced using fused deposition modelling (FDM) 3D printing, PolyJet, SLA, and DLP printers³⁵ and reported that the deviation ranged from low to high in a comparison between the PolyJet, DLP, and SLA printers, respectively. Lin et al. examined the dimensional changes of solid horseshoe-shaped models produced using DLP and SLA printers at different storage times.³⁶ A smaller margin of error (26 μ m) was observed in models produced by DLP, and there was a statistically significant difference in accuracy between the two printers. The findings of the Total Arch comparison in the current study are similar to previous research. In the four different designs, the models produced by the PolyJet, DLP, and SLA printers showed variations from low to high, respectively. The preferred layer thickness in printing, along with other production conditions, plays an important role in the accuracy of the 3D printed model. It is considered that the ideal layer thickness

Table III. Comparisons of Canine-Premolar Regions RMS values

Canine-Premolar Region (Right)						Canine-Premolar Region (Left)					
DLI ¹			Polyjet ²			SLA ³			DLI ¹		
Designs	Mean ± SD	Mean ± SD	Mean ± SD	p ¹	Post-hoc ¹	Designs	Mean±SD	Mean±SD	Mean±SD	p ¹	Post Hoc ¹
1 mm ^A (n = 10)	0.1 ± 0.02	0.15 ± 0.09	0.16 ± 0.10	0.238	—	1 mm ^A (n=10)	0.3 ± 0.15	0.14 ± 0.11	0.41 ± 0.19	0.002	2-3**
2 mm ^B (n = 10)	0.08 ± 0.01	0.06 ± 0.01	0.14 ± 0.06	0.002	1-2* 1-3* 2-3*	2 mm ^B (n=10)	0.16 ± 0.03	0.06 ± 0.01	0.15 ± 0.05	0.001	1-2** 1-3* 2-3*
3 mm ^C (n = 10)	0.07 ± 0.03	0.05±<0.01	0.10 ± 0.03	0.008	2-3**	3 mm ^C (n=10)	0.09 ± 0.02	0.05±<0.01	0.08 ± 0.01	<0.001	1-2** 2-3**
Solid ^D (n = 10)	0.07 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	<0.001	1-2*** 1-3***	Solid ^D (n=10)	0.06 ± 0.01	0.05 ± 0.01	0.05±<0.01	<0.001	1-2** 1-3**
p ²	0.003	<0.001	0.001			p ²	<0.001	0.001	<0.001		
Posthoc ²	A-C* A-D**	A-B**	A-D** B-D*			Posthoc ²	A-B*	A-B**	A-B**		
		A-C***					A-C***	A-C**	A-C**		
		A-D***					A-D*** B-D*	A-D**	A-D**		

*p < 0.05, **p < 0.01, ***p < 0.001.

p¹, Repeated measures ANOVA; p², One-way Anova Analysis; Post Hoc¹, Bonferroni Correction; Posthoc², Tukey's Test; SD, Standard Deviation.

Table IV. Comparisons of Molar Regions RMS values

Molar Region (Right)						Molar Region (Left)					
DLP ¹			Polyjet ²		SLA ³	DLP ¹			Polyjet ²		SLA ³
Designs	Mean ± SD	Mean ± SD	Mean ± SD	p ¹	Posthoc ¹	Designs	Mean ± SD	Mean ± SD	Mean ± SD	p ¹	Posthoc ¹
1 mm ^A (n = 10)	0.17 ± 0.02	0.36 ± 0.26	0.41 ± 0.13	0.033	1-3**	1 mm ^A (n = 10)	0.72 ± 0.30	0.26 ± 0.18	0.90 ± 0.35	<0.001	1-2** 2-3**
2 mm ^B (n = 10)	0.16 ± 0.04	0.10 ± 0.04	0.35 ± 0.08	<0.001	1-2** 1-3*** 2-3***	2 mm ^B (n = 10)	0.52 ± 0.06	0.10 ± 0.03	0.41 ± 0.13	<0.001	1-2*** 2-3***
3 mm ^C (n = 10)	0.15 ± 0.06	0.07 ± 0.01	0.32 ± 0.26	0.028	1-2* 2-3*	3 mm ^C (n = 10)	0.34 ± 0.05	0.08 ± 0.01	0.27 ± 0.05	<0.001	1-2*** 1-3* 2-3***
Solid ^D (n = 10)	0.13 ± 0.02	0.06 ± 0.02	0.12 ± 0.01	<0.001	1-2*** 2-3***	Solid ^D (n = 10)	0.25 ± 0.02	0.05 ± 0.01	0.13 ± 0.01	<0.001	1-2*** 1-3*** 2-3***
p ²	0.143	<0.001	<0.001			p ²	<0.001	<0.001	<0.001		
Posthoc ²	A-C* A-D**	A-B** A-C*** A-D***	A-D** B-D*			Posthoc ²	A-B* A-C*** A-D*** B-D*	A-B** A-C** A-D**	A-B** A-C** A-D**		

*p < 0.05, **p < 0.01, ***p < 0.001.

p1, Repeated measures ANOVA; p2, One-way Anova Analysis; Post Hoc1, Bonferroni Correction; Posthoc2, Tukey's Test; SD, Standard Deviation.

Table V. Percentages of resin amounts to be saved by using hollow models instead of solid models

Hollow Designs	DLP	Polyjet	SLA
1 mm	70.8%	37.4%	57.3%
2 mm	45.3%	26.8%	39.7%
3 mm	31.4%	15.5%	26.5%

for DLP printers (50 μm) and lower than SLA (100 μm) may result in more accurate model production.

Instead of a solid structure, dental models may be produced for diagnostic and study purposes in a hollow structure with different shell design options.^{16,25} The stability and durability of thin hollow models can be increased by adding a palatal bar or support structures of different geometries inside the model in the posterior region. Chanyawanta et al. produced hollow models in the shape of horseshoes with solid, grid-based, or gridless bases using LCD technology.¹⁶ The researchers stated that gridless hollow models with a shell thickness of 1 mm showed low accuracy, while models with a thickness of 3.0 mm exhibited acceptable accuracy.¹⁶ In the present study, a similar result was observed as there was no statistically significant difference in Total Arch RMS values between 3.0 mm hollow models produced by the Polyjet and SLA printers and the solid models. It is considered that using SLA for the production of thinner hollow models and adding a grid or palatal bar to the model base can improve accuracy. Therefore, hollow aligner models produced by an in-house method can exhibit higher resistance during the thermoforming process. However, it should be noted that each additional support structure requires greater planning and laboratory procedures.

The accuracy of 3D printing can vary depending on the geometry of the model. This variation is particularly important in aligner models that contain precise attachments located in different regions of the arch. Therefore, in the current study, the accuracy of the printed models was evaluated in 5 different regions. As a result, the variation level in the Anterior Region was significantly lower for all printers compared to the posterior regions, especially in the case of the hollow models. Previous studies have also reported higher variation levels in the posterior region compared to the anterior region,

which is consistent with the current findings.^{35,37} Various reasons have been proposed to explain this result. Lin et al. have suggested that the higher resin polymer density and polymer chain in the molar region may lead to increased dimensional changes during the polymerisation process.³⁶ The canine is centrally located and links the anterior and posterior of the dental arch. Dong et al. have indicated that the deformation observed in an object increases as it moves away from the centre, resulting in a greater deviation in the molar region.² It is thought that the anterior region exhibits greater dimensional stability than the posterior region, as it remains intact without the level of separation observed in the posterior region. While there is no angulation in the anterior region of the maxillary dental arch, the posterior region diverges into two separate segments, thereby exhibiting a divergence from the anterior region.

In the present study, the DLP printer demonstrated lower deviation for reduced shell thickness hollow models in the Anterior Region, while the SLA printer exhibited higher accuracy for solid models. Although there were statistically significant differences between printers and designs, the accuracy of all hollow designs was within clinically acceptable limits. In contrast to the present findings, Lin et al. reported that DLP printers showed lower variation in the anterior region compared to SLA printers for solid models.³⁶ Camardella et al. evaluated the accuracy of different base designs in solid models produced using SLA and PolyJet printers. It was observed that models produced using PolyJet technology exhibited minimal deviation in linear measurements in the anterior region and showed higher accuracy compared to SLA printers.³¹ The observed differences between the studies are thought to be influenced by factors related to the type of printer, the printing technology, resin formulations, variations in positioning on the print bed, and post-printing processes related to UV curing. These factors can contribute to variations in the final accuracy of the 3D printed models.^{31–35}

In the solid designs, the models produced using the Polyjet, SLA, and DLP technologies demonstrated the highest accuracy in the Molar Region. The use of Polyjet technology, which allows for a lower layer thickness (14–16 μm) compared to other techniques, is believed to contribute to achieving a smoother surface. Yoo et al. evaluated maxillary models produced using SLA, Multijet printing (MJP), and DLP printers in a solid structure using 3D digital surface superimposition.³⁴

Consistent with the present findings, the molar region demonstrated that MJP technology exhibited statistically significant greater accuracy compared to SLA and DLP technology. The authors noted that MJP's lower layer thickness compared to SLA may result in a higher resolution along the z-axis, which contributes to the superior accuracy.³⁴

It is noted that hollow working models produced by the different technologies, used in in-house clear aligner production, are subjected to pressure and heat application. Studies in this field are limited; however, Kenning et al. determined that hollow models produced by SLA printers with a shell thickness of less than 2.0 mm did not exhibit sufficient strength during the thermoforming process.¹⁹ In further research, it would be beneficial to evaluate the dimensional changes of hollow model designs under the thermoforming process and assess their impact on the accuracy of the appliance using the printing technologies employed in the present study.

Conclusion

Hollow designs can reduce the amount of resin required in model production. In the anterior region, all hollow designs are clinically acceptable, while for the molar region, only models produced by a PolyJet printer with a minimum shell thickness of 2 mm are considered appropriate. In the canine and premolar regions, the clinical accuracy of all hollow models produced using a PolyJet printer and those with a minimum shell thickness of 2 mm produced using DLP and SLA printers are considered acceptable. For the total arch, models with a shell thickness of 2 mm created using the PolyJet printer and 3 mm using DLP or SLA printers demonstrated accuracy within clinically acceptable limits compared to solid models.

Ethical approval

As this study did not involve any materials obtained from humans or animals, it therefore did not require ethical approval.

Conflict of interest

The authors declare that there is no conflict of interest.

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