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Comparative Evaluation of Surface Hardness and Accuracy of 3D-Printed DLP Model Resin Materials

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Abstract
Background It seems that the effect of three-dimensional DLP printing parameters on the surface hardness of printed model resins is neglected. **Objectives** The objective of the present study is to investigate and assess the surface hardness and dimensional accuracy of two different DLP model resin materials printed using one 3D printer machine. **Materials and Methods** Two different DLP 3D-printing resins were used to prepare a total of 20-disc specimens of (20×5)mm diameter and thickness respectively of (SENERTEK, Turkey), and (HARZ Labs, Russian) in addition to (CREALITY, China) as a control group (n=10). All specimens were printed using one 3D printer (CREALITY, HALOT, China) followed by the measuring of surface hardness (Shore D, China) and dimensional accuracy (Digital Vernier, China). **Results** ANOVA (Tukey HSD, post hoc) test was used for data analysis at a significant level of ($P \leq 0.05$). There was a significant difference in the surface hardness and dimensional accuracy of studied 3D-printed DLP model resins ($P \leq 0.05$). **Conclusion** Compared with CREALITY resin, the highest surface hardness was noticed in the experimental group of HARZ Labs followed by SENERTEK DLP model resins. All the DLP 3D-printed resin materials used in this study showed unstable dimensions when printed using the CREALITY HALOT printer machine.

Keywords: 3D printing; DLP; Surface hardness; Model Resin material.

Introduction

Additive 3D printing is one of the Computer-aided design-Computer aided manufacturing (CAD/CAM) digital concepts and it attracted more attention than the milling technique due to some advantages (Prasad et al, 2018; Kraemer Fernandez et al, 2020; Baba et al, 2021). These benefits include reduced material loss, no milling burs wear, and an easily reproducible prosthesis with precise features. Due to 3D printing production for more complicated shapes, the design possibilities are not limited (Reymus et al, 2020; Gad et al, 2022). 3D printing has been rapidly introduced and developed in medical and dental field due to applicable accuracy and reliability. The applications of 3D printing products were used in many aspects of health care including medical and dentistry devices (Revilla-León and Özcan, 2019; Jawahar and Maragathavalli, 2019; Baba et al, 2023). This method provides quick conversion of digital files of 3D models into physical items by first creating an STL (standard triangulation language) format and then printing 3D small-volume elements by either connecting, bonding, or polymerizing them (Prasad et al, 2018). Many variables must be controlled during the 3D printing process. Mechanical properties are influenced by the printed layer, thickness, the deepness of polymerization, shrinkage volume, and the volume and angle of the light source (Puebla et al, 2012). Understanding the numerous factors that determine the quality of the 3D printing product is crucial (Puebla et al, 2012; Coon et al, 2016; Ţălu, 2022).The most widely used 3D technologies in dentistry are Stereolithography (SLA), digital light projection (DLP), then fused deposition modelling (FDM), powder bed fusion (PBF), followed by laser powder forming and inkjet printing (Barazanchi et al, 2017; Akhila et al, 2019; Alshamrani et al, 2022). The main differences between the processes are the materials used and how the layers are joined to create the 3D object. However, SLA and DLP are the two most common 3D printing technologies in dental applications. SLA, which was first used for 3D systems in 1986, is a photopolymerization technology that uses a bath of photosensitive liquid resin and laser or an ultraviolet (UV) light to harden the material. This is to build up solid parts on a model-building platform in the form of multilayers (Alharbi et al, 2017; Pagac et al, 2021; Gad et al, 2022; Aati et al, 2022). This method›s layers are cured and joined to form a solid item. Whereas in the DLP 3D printing technology, the photopolymer resin is cured with a digital light projector rather than a laser (Kessler et al, 2020). DLP technology is comprised of a light-emitting diode (LED) that is projected as individual pixels throughout the entire projection surface layer, causing simultaneous curing (KEßLER et al, 2021; Unkovskiy et al, 2021). A liquid-based prototype system is constructed from the stereolithography file›s cross-sectional data (STL). This is the industry specification that all RP technologies must adhere to. The prototype model is constructed in a vat of photocurable resin on a platform which is lowered to a depth adequate for laser penetration just below the resin›s surface. The model is built in stages by using UV-emitting lasers to scan and cure the liquid surface of the photopolymer. The cross-section outlines are scanned first, followed by a hatch pattern scan to fill in the gaps. Photoinitiated polymerization produces a solid layer. The platform is then lowered to the previous depth beneath the resin surface, allowing one layer of resin to be swept across and scanned. The resin in liquid form provides no structural support, so supports must be constructed to support overhanging portions. Following the printing process, the model is approximately only cured up to 95% and is referred to as ‹green›. The product must next be cleaned with a chemical isopropanol bath and post-cured by being exposed to broad-spectrum UV radiation (Bletcher, 2016). DLP 3D printing is faster than traditional SLA because it prints and cures a single layer in seconds across the entire build plate. DLP has another benefit over SLA and other 3D printing technologies is that it consumes less material, lowering production costs. In the dentistry sector, DLP printing is currently being used to manufacture surgical guides, castable restorations, splints, and even interim crowns all made using digital imprints. DLP printing›s application in dentistry is projected to increase due to its speed and accuracy. However, there have been few studies examining the surface and mechanical properties of 3D-printed resin materials in dentistry, including surface hardness and accuracy. As a result, the production method, as well as the strength and polymerization ratio, are areas that demand additional investigation. Several factors, including accuracy, strength, printing speed, and layer thickness, may improve the dependability of 3D-printed materials for clinical and dental applications (Alharbi et al, 2016; Tahayeri et al, 2018; Shim et al, 2020), as well as curing procedures (Li et al, 2016; Osman et al, 2017). According to researchers, printing resin types, processes, and settings are all elements that influence the qualities of printed products (Tian et al, 2021). Oral structures and restorative materials are affected by their environment, and the oral environment is particularly problematic which can affect material qualities (Hao et al., 2018, Szczesio-Wlodarczyk et al., 2020). Following printing, the photopolymerized resin is cured in a UV light source. Some resins require post-processing light-curing treatment. This is used to cross-link unreacted monomers and finish the polymerization process after printing (Shumkov et al, 2020; Barragán-Paredes et al, 2021). The post-curing technique is intended to improve the mechanical properties of the printed object (Al-Dulaijan et al, 2022; Alshamrani et al, 2022) to ensure complete and uniform polymerization enhancing mechanical strength which improves the final mechanical properties (Reymus et al., 2019). The time required for the post-curing operation varies based on the photopolymerized 3D-printed resin and the parameters of the manufacturer. It is also significantly different from 3D printing to post-curing devices (Shin et al, 2018; Wu et al, 2019). The degree of conversion quantifies the quantity of polymerization (DC). As a result, higher DC improves mechanical characteristics and biocompatibility significantly (Perea-Lowery et al, 2021; Dantagnan et al, 2023). Many studies investigated different post-curing equipment resulting in significant mechanical differences in the final printed products (Reymus et al, 2019; Reymus et al, 2020; Perea-Lowery et al, 2021). A power analysis was not performed since no prior knowledge of the impact of the production method and storage conditions on 3D-printed dental cast dimensional accuracy and stability was available. As a result, greater research into the manufacturing process, including printing conditions and their impact on the mechanical properties of 3D-printed DLP material is required. Understanding how different parameters affect the mechanical characteristics of printed materials can assist in enhancing the quality and performance of dental restorations in regular application. 3D printing material selection for dental performance is determined by the end product›s intended application. The restorative materials must have strong mechanical qualities and extended biodegradation rates.

Materials and Methods

The disc-shaped specimen dimensions of 20×5mm diameter and thickness respectively were used to evaluate the surface hardness and dimensional accuracy (ISO 4049:2019), (Reymus and Stawarczyk, 2020). EXOCAD software system was used to design the disc specimens for 3D-printed resins (Yu et al, 2023). The STL file then exported to a 3D printing machine (DLP-CREALITY, HALOT, China). The model printing supports were produced automatically at the bottom of the disc-shaped specimens with 0.8mm tip diameter, 1.2mm support diameter, 0.50 density, and 6.0mm height. In the DLP printer›s build platform, this configuration was reproduced ten times, and ten identical specimen setups were created, Figure (1). To print all specimens in the same configuration, this design was saved and retrieved again to print the specimens in identical dimensions but with different study resin materials, Figure (2). After removing the printing support structures, the bottom-base surfaces of the specimens were ground with silicon carbide paper (800, 1500, and 2000 grit) and cleaned with alcohol as recommended by de Camargo et al., (de Camargo et al., 2021). The specimens were then post-cured using a light-cure unit for 4min (Silver Crest, Germany). Before the testing procedure, the specimens› dimensions and surface integrities were examined and stored in dark boxes for 48h at room temperature (25±1°C), Figure (3). For the hardness value, a Shore D (Shanghai, China) was used. A pyramid-shaped diamond indent was used to indent each specimen with a 50g force and a 30-second dwell duration at three different places per specimen, followed by average calculations (Aati et al, 2022), Figure (4). While the dimensional accuracy was measured using a digital vernier (China). One-way ANOVA (Tukey post-hoc Test, HSD) (SPSS-V23) was used to statistically analyze the data of surface hardness and dimensional accuracy. All p-values considered statistically significant at less than 0.05.

Figure(1):Ten identical specimen configurations A, designed using CAD, and B, printed in the DLP printer›s build platform

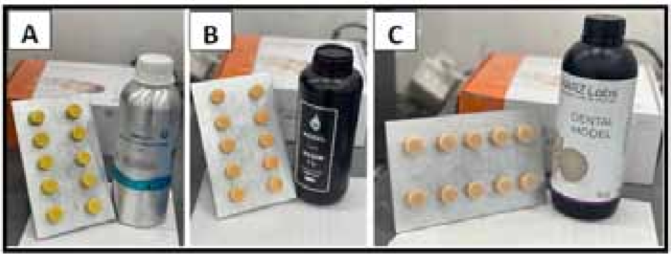

Figure (2): The specimens printed in identical dimensions by using different model resin materials; A, CREALITY; B, SENERTEK; and HARZ Labs

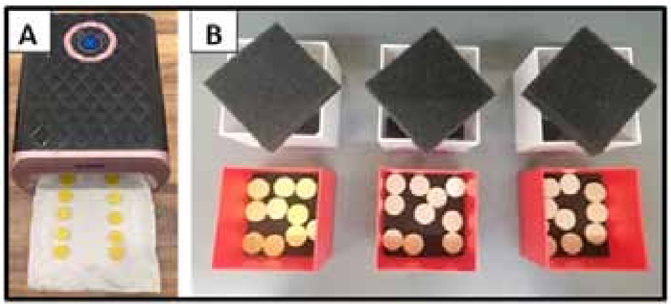

Figure (3): Specimens A, post-cured using a light-cure unit for 4min; and B, stored for 48h in dark boxes at room temperature (25±1°C)

Figure (4): Specimen under surface hardness (Shore D) tester unit

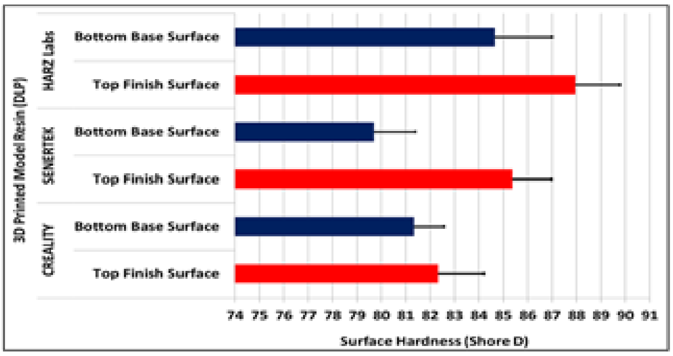

Figure (5): Bar Chart showing the mean surface hardness distribution of the 3D-printed study model resins

Results

Generally, there was a significant difference in the surface hardness of studied 3D-printed DLP model resins in terms of top finish and bottom base surfaces (P≤0.05). Furthermore, there was a significant difference in the surface hardness between both the top finish and bottom base surfaces of each SENERTEK and HARZ Labs and that of CREALITY DLP model resins, Figure (5) and Table (1). The highest mean value of the surface hardness test was in the top finish and bottom base surfaces of the experimental group of HARZ Labs followed by SENERTEK DLP model resins. In terms of thickness accuracy, the experimentally SENERTEK and HARZ Labs DLP model resins showed significant differences in the thickness accuracy in comparison to that of CREALITY as a control group (P≤0.001), Figure (6) and Table (2). However, concerning diameter accuracy, non-statistically significant differences were reported between the studied groups (P>0.05), except between that of HARZ Labs and CREALITY model resin which shows a significant difference (P≤0.05), Figure (7) and table (3).

Table (1): ANOVA (post-hoc, Tukey) test shows the surface hardness of the 3D-printed study model resins

Model Resin Surface	DLP/3D-Printed Resin		Mean Difference	Std. Error	P-Value	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Top Finish Surface	CREALITY	SENERTEK	-3.0500*	.54482	.000	S	-4.4008	-1.6992
		HARZ Labs	-5.6333*	.54482	.000	S	-6.9842	-4.2825
	SENERTEK	HARZ Labs	-2.5833*	.54482	.000	S	-3.9342	-1.2325
Bottom Base Surface	CREALITY	SENERTEK	1.6500*	.61719	.033	S	.1197	3.1803
		HARZ Labs	-3.4333*	.61719	.000	S	-4.9636	-1.9031
	SENERTEK	HARZ Labs	-5.0833*	.61719	.000	S	-6.6136	-3.5531

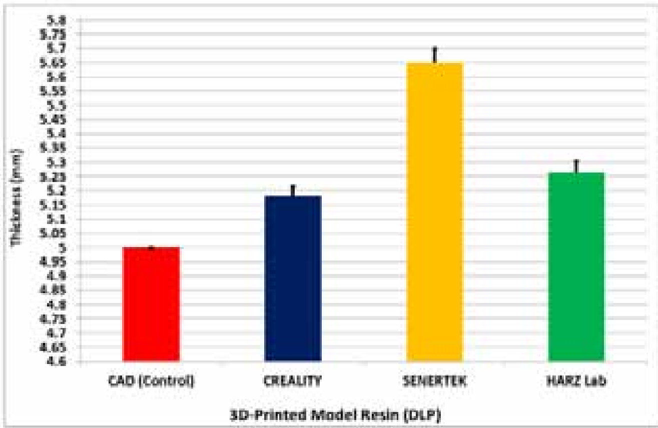

Figure (6): Bar Chart showing the mean distribution of specimens' thickness of 3D-printed study model resins

Table (2): ANOVA (post-hoc, Tukey) test shows the thickness of the 3D-printed study model resins

3D-Printed Model Resin		Mean Difference	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
CREALITY	SENERTEK	-.4690*	.01726	.000	S	-.5118	-.4262
	HARZ Labs	-.0830*	.01726	.000	S	-.1258	-.0402
SENERTEK	HARZ Labs	.3860*	.01726	.000	S	.3432	.4288

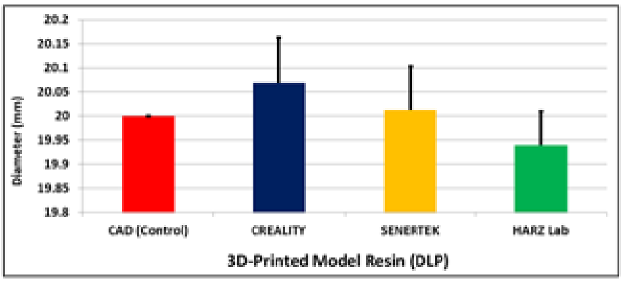

Figure (7): Bar Chart showing the mean distribution of specimens' diameter of 3D-printed study model resins

Table (3): ANOVA (post-hoc, Tukey) test shows the diameter of the 3D-printed study model resins

3D-Printed Model Resin		Mean Difference	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
CREALITY	SENERTEK	.0560	.03821	.323	NS	-.0387	.1507
	HARZ Labs	.1290*	.03821	.006	S	.0343	.2237
SENERTEK	HARZ Labs	.0730	.03821	.155	NS	-.0217	.1677

Discussion

The dental research community has been interested in additive technology because of the potential usage of digital applications in dentistry. As a result, comprehending the mechanical properties of the newer DLP 3D-printing model materials is essential for verifying the claims by the manufacturer, and for comparing them with conventional materials. Numerous factors might determine the quality of 3D-printed products. Different variables might affect the mechanical properties of the 3D-printed objects such as polymerization depth, layer thickness, amount of shrinkage, and the volume or light source angle (Puebla et al, 2012; Coon et al, 2016; Ţălu, 2022). The top finish and bottom base surfaces of HARZ Labs of DLP 3D-printed specimens model resin of show higher hardness followed by SENERTEK compared to that of CREALITY as a control group. Yet, there was a lesser surface hardness in the bottom base surfaces than the top finish surfaces of SENERTEK, HARZ Labs, and CREALITY respectively. The highest mean value of the surface hardness test was in the top finish and bottom base surfaces of the experimental group of HARZ Labs followed by SENERTEK DLP model resins. This might agree with a few studies they found that the post-printing curing could improve the mechanical properties of the printed resins (Al-Dulaijan et al, 2022; Alshamrani et al, 2022), It seems that the flashlight or UV light device indicates a higher degree of conversion in addition to the postpolymerization period that might have positively influenced the tested specimens. The emitting wavelength spectra of the postpolymerization UV devices may vary substantially. Since the flashlight operation mechanism has the largest spectrum, this could imitate a higher number of photoinitiators. This could explain why UV light devices despite their shorter operating duration produced better results (Reymus et al, 2020; Reymus et al, 2019). Significant differences also were between the tested post-photopolymerization specimens in terms of thickness and diameter dimensional parameters. An increase in the thickness was noticed within the SENERTEK and HARZ Labs DLP model resin specimens in comparison to the CREALITY control group. However, concerning specimen diameter, no differences were reported between the studied groups except in HARZ Labs which shows less discrepancy in diameter. Products created with 3D printing are built up layer by layer. The adhesive is important for the mechanical properties of all resin-based products. DLP printers polymerize each layer on the bottom of a resin-filled vat. As a result, the polymerization occurs in the absence of oxygen, and no oxygen inhibition layer may interfere with the attachment of the two layers. Consequently, additively made products exhibit a high degree of conversion immediately after the printing process, which is further enhanced by the use of postpolymerization equipment (Reymus et al, 2019; Reymus et al, 2020).

Conclusions

From using the CREALITY HALOT 3D-printer machine for DLP model resin, the following was concluded:

1. The higher surface hardness was in the top finish and bottom base surfaces of HARZ Labs followed by SENERTEK DLP model resins.
2. An increase in the DLP resin specimen thickness was reported in SENERTEK and then HARZ Labs compared to CREALITY resin.
3. The less diameter discrepancy was in HARZ Labs specimens compared to SENERTEK and CREALITY DLP model resins.

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