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Effect of post curing different temperatures on 3D denture hardness printed by DLP and LCD 3D printers

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Abstract

Post-curing temperature plays a vital role in enhancing the mechanical properties of denture base resins fabricated using 3D printing technologies such as Digital Light Processing (DLP) and Liquid Crystal Display (LCD) printers. In this study, the surface hardness of denture base specimens was evaluated following post-curing treatments at 60°C and 80°C. The results demonstrated that increasing the post-curing temperature significantly improved the hardness of samples from both printer types. DLP-printed samples showed greater improvements in hardness compared to LCD-printed samples across both temperature ranges. This difference is due to the higher energy exposure and more efficient photopolymerization of DLP systems. Both the LCD and DLP groups performed significantly better in hardness at 60°C compared to the control group. This indicates improved polymer bonding. Post-curing at 80°C produced the highest hardness values, particularly for the DLP group, suggesting that higher temperatures may help form denser polymer networks. Despite these benefits, it is important to take precautions to prevent material degradation or stress at higher processing temperatures. The results suggest that post-curing 3D-printed denture bases at 80°C may increase their surface hardness. Furthermore, DLP-produced materials perform better mechanically than LCD-printed ones.

Keywords: Denture, DLP, 3D denture hardness, 3D printers, LCD, temperature.

Introduction

Post-curing temperature significantly affects the degree of change in polymerization density and cross-linking in the resin matrix. This, in turn, changes the hardness of 3D-printed denture base materials (1). Partial polymerization often occurs in the first printing stage using LCD or DLP technologies, resulting from light attenuation and oxygen inhibition, leaving monomers in the final product (2). Post-curing at higher temperatures, such as 70°C and 90°C, makes unpolymerized methacrylate groups more reactive and the polymer chains move more freely, accelerating polymerization (3). At moderate temperatures, surface hardness increases significantly because the increased thermal energy facilitates cross-linking without compromising the structural integrity of the resin (4). When post-curing is conducted to a higher temperatures, the polymer network

becomes even more dense and rigid, leading to the highest observed hardness values (5). However, excessive heat may introduce internal stresses, brittleness, or degradation of the resin components, especially in materials not designed to withstand high thermal exposure (6). DLP printers, which provide higher light intensity and more uniform curing compared to LCD systems, generally yield denture bases with superior baseline mechanical properties and show a more pronounced increase in hardness after thermal treatment (7). Clinically, improved hardness enhances the durability, wear resistance, and polish ability of denture bases, contributing to their long-term performance (8). Therefore, careful selection of post-curing temperature particularly the use of 80°C for optimized results along with consideration of printer type, is essential to ensure the mechanical reliability of 3D-printed denture base prostheses. Despite the increasing use of 3D printing in dental prosthetics, there is limited comparative data on how different post-curing temperatures affect surface hardness across DLP and LCD technologies. Inadequate post-curing can compromise the mechanical performance of dentures, while excessive curing may cause material degradation. Another important factor affecting the final mechanical outcome is the interaction between resin content and post-curing temperature (9). When resin systems contain more cross-linking agents, such as urethane dimethacrylate (UDMA) or diacrylate derivatives, they tend to react better at higher temperatures. This makes them more stable and rigid (10). However, if resins with more flexible skeletons or lower cross-linking densities are subjected to excessively aggressive curing processes, they may experience thermal deformation or embrittlement (11).
The depth and uniformity of the initial cure significantly influence the additional benefits that post-heat curing can offer for DLP and LCD printers. DLP technology cures each layer simultaneously using high-intensity light, which results in more even conversion throughout the sample and allows heat treatment to reliably stiffen the material. On the other hand, LCD prints may exhibit uneven post-curing responses, especially at higher temperatures. This is because they do not emit as much light and their layers may not be consistent (12). From a clinical perspective, finding the right balance between surface hardness and toughness in highly rigid dentures is crucial. This is because highly rigid dentures may fracture under functional stress. To produce strong and durable dentures, it is important to find the right balance between printer settings, post-cure temperature, and time (13). Review of literature regarding the effect of post curing different temperatures on 3D denture hardness printed by DLP and LCD 3D printers revealed scarce publications. Therefore, this study designed to evaluate and compare the effects of two common post-curing temperatures (60°C and 80°C) on the surface hardness of denture base resins fabricated using both DLP and LCD 3D printers. Additionally, to identify an optimal curing condition that balances enhanced mechanical performance with material safety and consistency across printing methods.

Materials and Methods

Ethical approval

This study approved by Medical Ethics Committee / Middle Technical University
Reference Number: MEC : 123 (Date: 07/05/2025)

Specimens collection and preparation

Forty eight specimens of light-cured resin materials (Figure. 1) used as provisional restorations were 3D-printed (20 x 10 x 5 mm) referring to ISO 4049 (1). The specimens were divided into two groups as (DLP 3D printed group and LCD 3D printed group) (Figure.2). These groups were further divided into three subgroups based on their heat curing treatment As (8 control, 8 for 60 ^{O} C and 8 for 80 ^{O}C). In the current study, the Arma resin was used as a denture base.

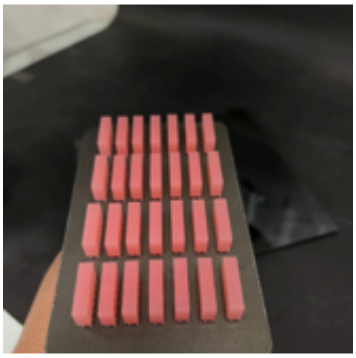

Figure 1. Showed the specimens of the study

Figure2.A) ASIGA Printer Max DLP, and B)LCD 3D printer (CREALITY company)

Computer aided design (CAD)

The designing procedure was started by'NEW' phase, while the information of the restoration such as name and number of specimens were recorded and saved, then the type of restoration (complete denture) and the material used (PMMA) also were selected as shows in Figure. 3. The second phase was "SCAN" phase, from "ACTION" menu in which digital images were obtained by scanning each stone die by the extraorally scanner (vinyl 3D scanner; smart optics) which is already saved in the computer. The third phase was designing of the denture base in "DESIGN" phase, which model analysis is the main step in this phase which was automatically detected by the system with simple modification may be needed for anatomical landmarks. The undercut was checked and the path of insertion was determined, the denture margin line was also determined as used to determine margins of crown as shown in Figure. 4. Consequently, each technique will carried out by the machines and instruments according to described techniques.

Digital data resolution

The digital data were exported in STL format by dental scanner Then, the STL file of sample was imported to DLP 3D and LCD 3D printers software (Figure. 5).

3D Printing

The manufacturing workflow for vat-polymerization materials 3D printers consist of three steps: 3D print manufacturing, washing, and post-curing process wherethe specimens was placed in glycerin pure vegetable (coconut oils) pureglycerin is colorless and odorless liquid inside container to improve the polymerization by inhibitor oxygen and making post curing as it comes as shown as in Figure (6. A and B) (14).

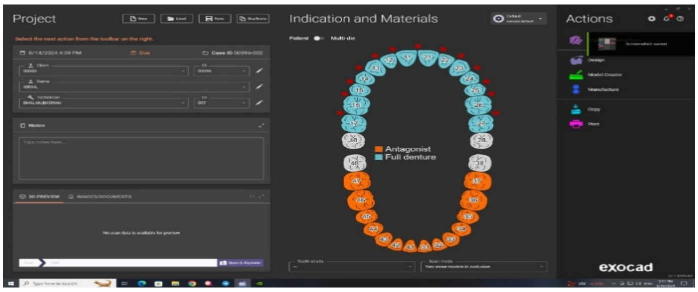

Figure 3. The profile of exocad program

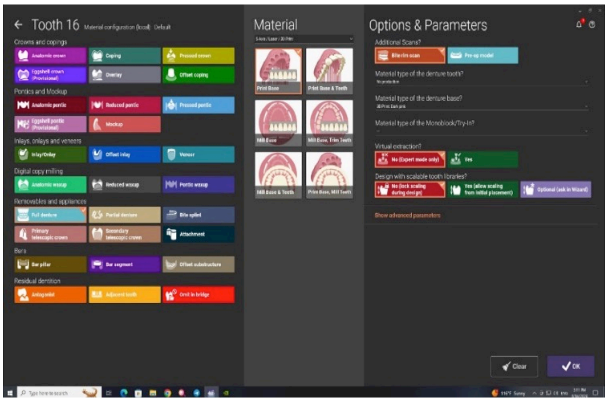

Figure 4. Actions in exocad program

I. First group was control group post curing without heat
II. Second group post curing by 60^{0}C.
II. Third group post curing by 80^{0}C.

Figure. 5: Shows the Exocad Softwar

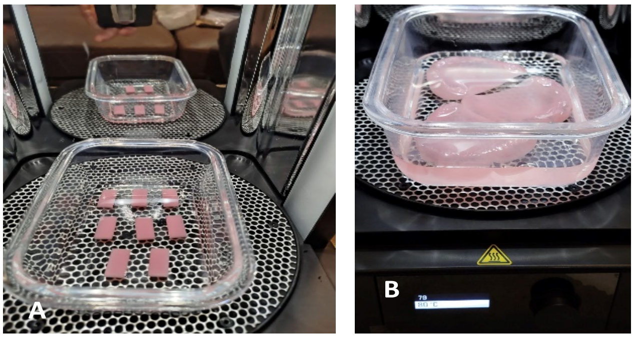

Figure. 6: Post curing process at A. 60^{0}C and B. 80^{0}C curing degrees for specimens in in glycerin

Finishing

After completed post curing, the supported structure was removed by sand paper (800,1500 and 2000 grit) as display in Figure. 7. Finally, the pumice was used to polish this process from one side to imitate complete denture, which was washed by water (15). The final shape for specimens before mechanical test was appeared in Figure. 8.

Hardness test

3D samples from (1-8), they were treated with 60 °C . The 3D samples from (9-16), they were treated with 80 °C . The specimens were kept for 24 hours in an incubator at 37 ℃ and not thermos-cycled, then they were thermos-cycled for a total of 5000 cycles between 5 ℃ and 55 ℃ with a dwell time of 60 seconds and a transfer time of 30 seconds, subjected to 5,000 cycles of thermocycling (SD Mechatronik Thermocycler; SD Mechatronik GmbH, Westerham, Germany) then they were tested again. The device shown in Figure.9 is a Shore D hardness tester, commonly used to measure the hardness of rigid polymers and hard plastics, such as those used in denture base materials (Figure.10). The setup includes an electronic digital Shore D durometer, which displays the hardness value based on the resistance of the material to indentation. In this case, the durometer is integrated into a hydraulic press to ensure uniform and controlled application of force, minimizing operator error and enhancing measurement accuracy (16). The Shore D scale is suitable for harder materials and uses a pointed indenter under a specific load to assess the depth of indentation. A material is stiffer and less susceptible to deformation if its Shore D value is higher (17). This equipment is essential for comparing denture materials and ensuring their quality. It is often used to examine the mechanical properties and surface hardness of cured resin samples in dental laboratories and materials research.

Figure.7: Shows method of removing the Support Structure by sand paper

Figure. 8: The labeling and saving of denture bases before testing

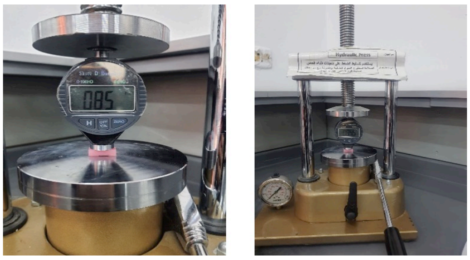

Figure.9 : Shows the Shor D hardness tester

Figure.10. Resin specimens after 3D printing ready for hardness test

Statistical Analysis

The data were presented graphically using Microsoft Excel 2016, and the Statistical Package for the Social Sciences (SPSS) version 26 was used for statistical analysis. The analysis comprised both descriptive and inferential statistics.

Results and Discussions

Hardness Descriptive Statistics of LCD and DLP 3D Printers

Table. 1. presents the descriptive statistics for the surface hardness test conducted on three groups exposed to different post-cure temperatures: Control, DLP 60°C, and DLP 80°C. The mean surface hardness values show a clear increasing trend with temperature: 76.42 for the Control group, 86.38 for the DLP 60°C group, and 89.37 for the DLP 80°C group. This indicates that post-curing significantly enhances the surface hardness, with the highest hardness observed at 80°C. The standard deviation values are relatively low across all groups, suggesting consistent measurements, although slightly more variation was noted at the highest temperature. The range of hardness values also shifts upward with increasing temperature, confirming the positive impact of thermal post-curing. Overall, the data demonstrate that higher post-cure temperatures improve surface hardness, with LCD 80°C being the most effective condition among those tested.

Table 1. DLP 3D printer descriptive statistics of the surface hardness test at different post-cure temperatures

Groups	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	8	76.4166	.95526	.33773	74.67	77.33
DLP 60°C	8	86.3750	.91592	.32383	84.67	87.33
DLP 80°C	8	89.3749	1.23994	.43839	87.67	91.00
Total	24					

The changes in the structure and chemical composition of the resin that occur during post-heat curing are what cause the results shown in Table (1). When optical methods are first used to cure a resin, the polymerization process may not be complete. This means that there are still unreacted polymer chains and monomers remaining in the structure (18). Post-curing at high temperatures (e.g., 80°C) enhances the degree of cross-linking of the polymer by initiating more chemical reactions. This results in a thicker and stiffer polymer network, significantly improving the mechanical properties of the material, particularly its surface hardness. Heating also makes the molecules more mobile, helping the polymer chains adhere better to each other and making the curing process more even (19). This results in a stronger and more stable surface structure (18). Heat also reduces the amount of residual monomers, which would normally make the material softer. These combined effects (20) may explain why surface hardness increases with post-curing temperature, with 80 °C showing the greatest change. Table.1 illustrates a variety of basic chemical and physical mechanisms that cause surface hardness to increase with increasing post-curing temperature. Because not all monomers are fully polymerized during the initial photocuring stage, residual monomers remain, and insufficient crosslinking occurs in the polymer matrix. Post-curing at high temperatures, such as 80°C, increases the degree of conversion and makes the polymer network more cross-linked by providing the necessary heat for the polymerization process to complete (21). This high crosslinking density makes the material stiffer and tougher by reducing molecular mobility. It also improves its mechanical properties, such as surface hardness (18). Furthermore, residual monomers, which act as softeners and make the material more malleable, are easily removed by heat. This removal further increases hardness. Thermal post-curing, performed using mild annealing, also helps improve structural order and relieve internal stresses generated during the initial curing cycle. This makes the surface stronger and more balanced. Moreover, elevated temperatures ensure that the surface layers, which may have been under-cured during light exposure, are fully polymerized, resulting in a harder and more durable outer surface (22). Collectively, these factors explain why higher post-cure temperatures lead to significantly improved surface hardness, with 80°C yielding the most effective results among the tested conditions. Figure (11) presents a bar chart illustrating the mean surface hardness values for specimens subjected to different post-cure temperatures: Control (no post-cure), DLP 60°C, and DLP 80°C. The chart clearly demonstrates a significant and consistent increase in surface hardness with rising post-curing temperatures. The Control group exhibited the lowest mean hardness value of 76.4166, while the DLP 60°C group showed a marked improvement, reaching a mean value of 86.375. The highest surface hardness was recorded in the DLP 80°C group, with a mean of 89.3749, indicating further enhancement over the 60°C condition. The distinct separation between the bars reflects the positive correlation between post-cure temperature and surface hardness. These findings suggest that thermal post-curing, particularly at 80°C, plays a critical role in optimizing the mechanical performance of the material by significantly increasing its surface hardness.

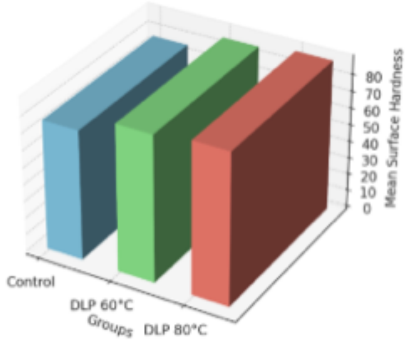

Figure.11: DLP 3D printer Bar-Chart of the mean value of surface hardness test at different post-cure temperatures

Table. 2 shows the descriptive data for the surface hardness test conducted on three groups using LCD digital processing technology and different post-curing temperatures: the control, the 60°C LCD, and the 80°C LCD. The results clearly show that as the post-curing temperature increases, the surface hardness increases. The average surface hardness of the 60°C LCD group increased to 85.1249, which was a significant change. On the other hand, the control group had the lowest value at 75.2916. The 80°C LCD group had the highest average value, at 87.7916. The 80°C LCD group had high hardness and lower variability (standard deviation = 1.03779), meaning the data were more consistent. The 60°C LCD group had a higher standard deviation (2.81119), meaning the data were more variable. The minimum and maximum values also increased with temperature, further confirming the positive effect of thermal post-curing. Overall, these results indicate that higher post-cure temperatures significantly enhance the surface hardness of LCD -printed specimens, with 80°C proving to be the most effective and reliable condition among those tested.

Table.2: LCD 3D printer descriptive statistics of the surface hardness test at different post-cure temperatures.

Groups	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Control	8	75.2916	.74413	.26309	74.00	76.67
LCD 60°C	8	85.1249	2.81119	.99391	79.00	87.67
LCD 80°C	8	87.7916	1.03779	.36691	86.00	89.33
Total	24					

The results presented in Table (2), showing a clear increase in surface hardness with higher post-cure temperatures in LCD -printed specimens, can be attributed to several key factors related to polymer chemistry and thermal post-processing behavior. Digital Light Processing (LCD) relies on light-induced polymerization to solidify resin materials; however, the initial light-curing process may not fully complete the polymer network formation. As a result, some monomers and oligomers remain unreacted, leading to a partially cured structure that is softer and less mechanically stable (23). High temperatures, especially 80°C, during post-processing promote cross-linking and improve the conversion of these remaining molecules into a solid polymer matrix. The improved mechanical strength and surface hardness demonstrated in the data are directly attributable to the resulting denser, more interconnected polymer network (22). Heat also makes the molecules move more freely, helping the polymer chains align and respond better. This increased mobility helps the curing process be more consistent and thorough, especially in areas that would otherwise be less exposed during the initial printing (21). The low standard deviation demonstrates that post-curing temperatures of 80°C are ideal for promoting ample cross-linking while minimizing internal stress. This not only makes the material stiffer but also ensures it is more uniform throughout. Also, the thermal energy at higher temperatures may help relieve any residual tension and make the polymer structure more stable and compressive through moderate annealing effects. The 80°C LCD set had a higher and more consistent surface hardness. This is likely due to the effects of both temperature and chemicals working together. This demonstrates how important it is to perform proper post-curing to improve the mechanical performance of LCD-printed materials.

Figure. 12 shows a graph comparing the average surface hardness values of samples processed using LCD technology at different temperatures. The chart clearly illustrates a substantial and progressive increase in surface hardness with rising post-curing temperatures. The Control group, which underwent no post-curing, exhibited the lowest mean hardness at 75.2916. In contrast, the LCD 60°C group demonstrated a marked improvement, with a mean hardness of 85.1249. The highest surface hardness was observed in the LCD 80°C group, reaching 87.7916, indicating the most effective enhancement. The color-coded bars effectively highlight the differences among the groups. The clear visual distinction in bar heights underscores the positive impact of thermal post-curing, particularly at 80°C, on improving the mechanical properties of the printed material. This graphical representation reinforces the statistical findings and supports the conclusion that increasing the post-cure temperature significantly enhances surface hardness.

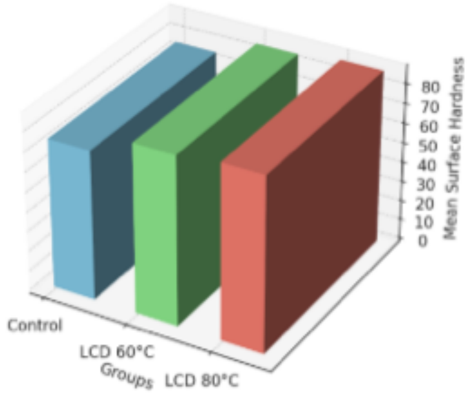

Figure 12. LCD 3D printer Bar-Chart of the mean value of surface hardness test at different post-cure temperatures.

A comparison between the surface hardness results of LCD and DLP printing technologies, as presented in Tables (1) and (2), reveals that both methods show similar baseline values in the Control groups, indicating comparable initial curing performance. However, as the post-cure temperature increases, notable differences emerge between the two. At 60°C, the DLP printer produces a slightly higher mean surface hardness (86. 38) compared to the LCD printer (85.12), and it also exhibits greater consistency, as reflected by a lower standard deviation (0.92 vs. 2.81). This suggests that DLP printing responds more efficiently and uniformly to moderate thermal post-curing. At 80°C, the trend continues with DLP again achieving a higher mean hardness value (89.37) than LCD (87.79), although the DLP printer shows improved consistency at this higher temperature, with a slightly lower standard deviation (1.04 vs. 1.24). Overall, both technologies benefit significantly from increased post-cure temperatures, but DLP printing demonstrates a marginal advantage in achieving higher hardness values, while LCD printing shows better uniformity and reliability at the highest curing condition tested. This findings agree with (24,25) studies ,and disagree with (26) study.

One–way ANOVA test for LCD and DLP 3D Printers

Table. 3 presents the results of a one-way ANOVA test conducted to determine whether there are statistically significant differences in surface hardness among groups subjected to different post-cure temperatures. The ANOVA results indicate a very high F-value of 335.780 with a corresponding p-value (Sig.) of .000, which is far below the conventional alpha level of 0.05. This result is statistically significant, as denoted by the (S) symbol. The Sum of Squares Between Groups is 736.226, while the Sum of Squares Within Groups is 23.022, indicating that the vast majority of the total variance (759.248) is attributable to differences between the groups rather than random variation within them. The degrees of freedom (df) for between-group comparisons is 2, and for within-group comparisons is 21.

Table. 3: One–way ANOVA test of DLP 3D printer for the surface hardness test at different post-cure temperatures.

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	736.226	2	368.113	335.780	.000

Within Groups	23.022	21	1.096		(S)
Total	759.248	23			

The ANOVA analysis strongly confirms that the differences in mean surface hardness across the different post-cure temperature groups are statistically significant. This supports the interpretation that post-curing temperature has a significant effect on the surface hardness of the material. Further post-hoc analysis (e.g., Tukey HSD) would be appropriate to identify which specific group comparisons are significantly different from each other. The statistically significant results observed in the ANOVA analysis can be attributed to the fundamental chemical and structural transformations that occur in the resin material during post-curing (27). Initially, the photo-curing process whether by LCD or DLP may leave a portion of the monomers and oligomers unreacted, resulting in incomplete polymerization and reduced mechanical properties, such as surface hardness (27). Post-curing at elevated temperatures activates further polymer cross-linking, increases the degree of monomer conversion, and reduces the presence of residual, softening agents like unreacted monomers. These chemical changes lead to the formation of a denser and more rigid polymer matrix, which enhances the surface hardness of the material (28). As the post-cure temperature rises from room temperature to 60°C and then to 80°C, the additional thermal energy accelerates the curing reactions and improves the mobility of polymer chains, allowing for more uniform and thorough cross-linking. This results in distinct and progressively higher hardness values across the groups, which the ANOVA test captures as statistically significant differences in the means. The high F-value and low p-value indicate that the variation in surface hardness is primarily due to differences in temperature treatment rather than random chance. Therefore, the ANOVA results confirm that post-curing temperature is a critical factor influencing the mechanical performance of the material, justifying the need for post-hoc tests to pinpoint which temperature intervals contribute most significantly to the observed effects. Table. 4 displays the results of a one-way ANOVA test conducted to assess whether there are statistically significant differences in surface hardness among groups treated with different post-cure temperatures. The analysis shows a Sum of Squares Between Groups of 693.478 with 2 degrees of freedom (df), resulting in a Mean Square Between Groups of 346.739. The Sum of Squares Within Groups is 66.735 with 21 df, yielding a Mean Square Within Groups of 3.178. The calculated F-value is 109.112, and the significance level (p-value) is .000, which is highly statistically significant (as indicated by the symbol (S)). This means the probability that these differences occurred by chance is virtually zero.

Table 4. One–way ANOVA test of LCD 3D printer for the surface hardness test at different post-cure temperatures.

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	693.478	2	346.739	109.112	.000 (S)
Within Groups	66.735	21	3.178		
Total	760.213	23			

Hardness comparison test for LCD and DLP 3D Printers

Table (5) presents the results of the DLP post-hoc comparison test for the surface hardness test across different post-cure temperature groups. The analysis reveals statistically significant differences between all group comparisons at the 0.05 significance level. Specifically, the mean surface hardness of the DLP 60°C group was significantly higher than that of the Control group, with a mean difference of -9.95338 and a p-value of .000. Similarly, the DLP 80°C group demonstrated an even greater improvement over the Control group, with a mean difference of -12.95825 and a p-value of .000. Moreover, a significant difference was also observed between the DLP 60°C and DLP 80°C groups, with the latter exhibiting superior surface hardness (mean difference = -2.99987, p = .000). The 95% confidence intervals for all comparisons did not include zero, further confirming the statistical significance of the differences. These findings indicate that each increase in post-cure temperature leads to a substantial and statistically significant enhancement in surface hardness, with the highest values achieved at 80°C.

Table 5. DLP3D printer Comparisons test of the surface hardness test at different post-cure temperatures studied groups.

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Control	DLP 60°C	-9.95838-*	.52352	.000	S.	-11.0471-	-8.8697-
	DLP 80°C	-12.95825-*	.52352	.000	S.	-14.0470-	-11.8695-
DLP 60°C	DLP 80°C	-2.99987-*	.52352	.000	S.	-4.0886-	-1.9112-

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

The statistically significant results observed in Table. 5 can be explained by the fundamental effects of heat on the polymerization and cross-linking processes in the DLP -printed resin material. During the initial photo-curing stage, not all monomer chains fully react, leaving behind unpolymerized components and a loosely formed polymer network. Post-curing at elevated temperatures, such as 60°C and 80°C, provides the additional thermal energy required to activate residual photo-initiators and monomers, leading to increased polymer chain growth and cross-linking density (28). This results in a more compact and rigid polymer matrix, which directly contributes to increased surface hardness. The significant mean differences between all group comparisons reflect the progressive improvement in polymer structure as curing temperature rises. For instance, the substantial difference between the Control and 60°C group indicates that even moderate heating enhances polymer conversion. The even greater difference between the Control and 80°C group shows that higher temperatures further optimize the mechanical integrity of the material. Additionally, the statistically significant difference between the 60°C and 80°C groups demonstrates that the effect of temperature is not only present but continues to be beneficial as it increases, albeit to a lesser extent. The fact that all 95% confidence intervals exclude zero confirms that these differences are not due to random variation but are instead caused by real changes in the material properties resulting from temperature-dependent chemical reactions (31). In summary, these results occur because post-curing at higher temperatures improves the degree of polymerization, reduces residual monomers, and enhances structural uniformity all of which contribute to a statistically and practically significant increase in surface hardness, with 80°C producing the most robust outcomes. Table (6) displays the results of a post-hoc comparison test using the LCD method to examine differences in surface hardness across various post-cure temperature groups. The analysis shows that all pairwise comparisons are statistically significant at the 0.05 level. The mean surface hardness for the LCD 60°C group was significantly higher than that of the Control group, with a mean difference of -9.83325 and a p-value of .000. An even greater difference was observed between the Control and LCD 80°C groups, with a mean difference of -12.50000 and a p-value of .000, indicating a substantial increase in surface hardness with higher post-cure temperature. Furthermore, the comparison between the LCD 60°C and LCD 80°C groups also showed a significant difference (mean = -2.66675, p = .007), confirming that the 80°C treatment yields better results than 60°C. The 95% confidence intervals for all comparisons do not cross zero, reinforcing the significance of these differences. Overall, the data confirm that increasing the post-cure temperature in LCD -printed specimens leads to a statistically significant improvement in surface hardness, with the highest enhancement achieved at 80°C.

Table 6. LCD Comparisons test of the surface hardness test at different post-cure temperatures studied groups

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	P-Value	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Control	LCD 60°C	-9.83325-*	.89132	.000	S.	-11.6869-	-7.9796-
	LCD 80°C	-12.50000-*	.89132	.000	S.	-14.3536-	-10.6464-
LCD 60°C	LCD 80°C	-2.66675-*	.89132	.007	S.	-4.5204-	-.8131-

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

The statistically significant results reported in Table (6) arise from the fundamental thermal effects of post-curing on the polymerization process in LCD-printed specimens. Digital Light Processing (LCD) relies on photo-curing to initiate polymerization, but this process often leaves a portion of the resin incompletely cured, especially in deeper layers or areas with limited light exposure (32). When subjected to elevated post-cure temperatures such as 60°C and 80°C the resin undergoes further polymerization and increased cross-linking of polymer chains. This thermal activation promotes a more complete reaction of residual monomers and enhances the structural density of the cured material (31). As the post-cure temperature increases, the material develops a more tightly packed and mechanically stable polymer network. This transformation is responsible for the significant increases in surface hardness observed across the group comparisons (33). The difference between the Control and 60°C groups reflects the initial benefit of thermal activation, while the larger difference between the Control and 80°C groups highlights the compounded effect of higher temperature in achieving more robust curing. Additionally, the significant difference between the 60°C and 80°C groups indicates that the post-curing process continues to enhance material performance even at higher temperatures, though the gains may begin to taper off.

The 95% confidence intervals not crossing zero reinforce that these differences are statistically valid and unlikely due to random variation. In essence, these results occur because thermal post-curing significantly improves the chemical completeness, uniformity, and mechanical integrity of the LCD -printed polymer, resulting in progressively higher surface hardness as the curing temperature increases, with 80°C yielding the most optimal outcome. A comparison between the LCD and DLP printers reveals that both technologies exhibit a similar trend: surface hardness significantly increases with higher post-cure temperatures. However, there are notable differences in the magnitude and consistency of the results across the two systems, particularly as shown in the post-hoc analysis tables (Tables 5 for DLP and 6 for LCD). In terms of mean differences, the DLP printer shows slightly larger improvements in surface hardness across all group comparisons. For example, the mean difference between the Control and 80°C group is -12.95825 for DLP, compared to -12.50000 for LCD. Similarly, the difference between the 60°C and 80°C groups is -2.99987 for DLP, slightly greater than -2.66675 for LCD. This suggests that DLP printing may be more responsive to thermal post-curing, producing marginally higher hardness values.

However, the standard deviations in the tables above indicate that results are more consistent and variable for DLP technology at the highest post-curing temperature. DLP technology has somewhat narrower confidence intervals and less variability at 80°C, indicating a more reliable and stable thermal curing process. However, both printers show statistically significant differences at the 0.05 level.

Conclusions

The results of the current study indicated that the surface hardness of 3D-printed denture base resins produced using LCD and DLP technology was significantly affected by post-curing temperature. Post-heat curing at 80°C yielded optimal hardness results in all experimental groups, highlighting the significant effect of elevated temperatures in promoting polymer bonding and improving mechanical properties. The significant improvement in hardness of DLP-manufactured samples, compared to LCD-manufactured samples, is attributed to the increased light exposure efficiency and polymerization stability during DLP printing. On the other hand, LCD-printed samples exhibited lower contrast after post-curing at 80°C, indicating that they are more stable when handled at high temperatures. These results highlight the importance of customizing post-curing methods to meet the specific needs of each printing method. From a clinical perspective, adjusting post-curing parameters may enhance the structural integrity, corrosion resistance, and durability of denture bases, ultimately leading to improved denture treatment outcomes and increased patient satisfaction. Future studies should investigate extended curing times, varied temperature ranges, and the effects of different resin formulations to enhance post-curing methods for additively manufactured dental applications.

Declarations

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Ethics statement

The authors confirm that this research complies with the journal's ethical approval requirements and has been prepared in accordance with the ethical guidelines stated on the journal's author guidelines page.

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Competing interest's statement

The authors declare that they have no conflict of interest.

Author contributions

INY provided the concepts and revised the manuscript. IMH worked with laboratory works, data collection and analysis, and writing the manuscript draft.

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