Long-term Stability of 3D Printed Orthodontic Models Under Various Storage Conditions

2024 Research Aid Awards (RAA)

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FollowUp Form

Award Information

In an attempt to make things a little easier for the reviewer who will read this report, please consider these two questions before this is sent for review:

- *Is this an example of your very best work, in that it provides sufficient explanation and justification, and is something otherwise worthy of publication? (We do publish the Final Report on our website, so this does need to be complete and polished.)*
- *Does this Final Report provide the level of detail, etc. that you would expect, if you were the reviewer?*

Title of Project:*
Long-term Stability of 3D Printed Orthodontic Models Under Various Storage Conditions

Award Type
Research Aid Award (RAA)

Period of AAOF Support
July 1, 2024 through June 30, 2025

Institution
The Research Foundation for SUNY on behalf of University at Buffalo

Names of principal advisor(s) / mentor(s), co-investigator(s) and consultant(s)
Ashish Gurav, Steven Makowka, Stephen Warunek

Amount of Funding
$5,356.00

Summary/Abstract*

(Referring to your original abstract, summarize the findings of your project)

Long-term Stability of 3D Printed Orthodontic Models Under Various Storage Conditions: Abdullah A, Makowka S, Warunek S, Gurav A
Introduction: Orthodontic treatment involves not only achieving successful treatment outcomes but also ensuring that the results last over me. Retention on and prevention of relapses are key aspects of a successful orthodontic treatment. Accurately fi ng orthodontic retainers are critical in ensuring the stability of treatment outcomes. In recent years, digital dentistry has revolutionized the process of creating retention on appliances, particularly vacuum-formed overlay retainers. This shift has enabled orthodontists to scan dental arches to produce 3D printed resin models, replacing traditional alginate impressions and stone models. These advancements have not only increased accessibility but also reduced the me and resources required for creating retainers. However, an important question arises regarding the long-term stability of these 3D printed models under various storage conditions. While manufacturers regularly test the quality of 3D-prin ng resins over short periods of me, there is a lack of independent research on the long-term stability of 3D printed models. Ensuring the accuracy of these models over me is crucial for creating replacement retainers that maintain their effectiveness. This study aims to fill this gap by evaluating the long-term stability of orthodontic models 3D-printed using two different resins materials under various storage conditions. Findings from this study will provide evidence based recommendations for optimal storage conditions for the 3D printed models as well as provide insights into the choice of 3D-prin ng resin material, ultimately enhancing the accuracy of retention appliances and preventing relapse. This pioneering study holds great relevance, promising to establish guidelines that ensure the quality and safety of these technologies for the benefit of both pa ents and orthodontists.
Study Objectives: The primary objective of this study is to evaluate and compare the long term stability of 3D printed orthodontic models that have been stored, relative to the initial printed models. This study will also evaluate the effect of various storage conditions (temperature, humidity, light exposure) on the stability of 3D printed orthodontic models.
Hypothesis: (I): 3D printed orthodontic models will not experience any dimensional stability alterations over the course of 12 months regardless of their storage conditions. (II): Models 3D-printed using Dra Resin and Model Resin exhibit no differences among their dimensional stability over the course of 12 months regardless of their storage conditions.
Methods: 3D printed models will be generated using two different resin materials (FormLabs Draft Resin and Model Resin). These models will be subjected to various storage conditions, including dark and light exposure, as well as various storage temperatures (0°C, 23°C, 50°C) to mimic real world storage scenarios for the models. We will use scanning and metrology software to track dimensional changes in the models at specific me intervals (1,3,6,12 months) and compare them to the respective scans obtained from the model immediately following 3D printing.
Clinical Implications: The clinical implications of this study on the long-term stability of 3D printed orthodontic models include the potential to establish evidence-based storage guidelines, leading to more accurate and reliable retainers. This study will provide critical evidence to enhance treatment outcomes, reduce costs and time associated with retainer replacements, and ensure quality assurance in orthodontic practices. Additionally, the study may promote wider adoption of 3D printing technology in orthodontics, benefiting both practitioners and patients.

Respond to the following questions:

Detailed results and inferences:*

If the work has been published, please attach a pdf of manuscript below by clicking "Upload a file".
<u>OR</u>
Use the text box below to describe in detail the results of your study. The intent is to share the knowledge you have generated with the AAOF and orthodontic community specifically and other who may benefit from your study. Table, Figures, Statistical Analysis, and interpretation of results should also be attached by clicking "Upload a file".

Abdullah, Alaa 2024 RAA figures & tables.pdf
Material composition:
The FTIR analysis for Draft Resin revealed characteristic absorption bands indicative of its molecular composition. The infrared spectrum exhibited prominent peaks corresponding to O-H stretching, C-H stretching in alkanes, and C-H stretching in methyl groups, respectively. Additional peaks were noted, suggesting the presence of carbonyl groups (C=O) and aromatic compounds in the material. The peaks analysis further detailed the transmittance values for these and other significant peaks, providing a comprehensive profile of the sample's functional groups. The FTIR analysis for Model resin, revealed key absorption bands indicative of its molecular composition. The infrared spectrum exhibited prominent peaks indicating C-H stretching in alkanes. Additional peaks were observed, suggesting the presence of carbonyl groups (C=O), and aromatic compounds.
The SEM-EDS analysis reveals distinct compositional differences between the Model resin and Draft resin samples. The EDS spectra for Model resin indicates a strong presence of Silicon (Si) alongside Carbon (C). In contrast, the Draft resin sample shows a dominant Carbon (C) peak. The Draft resin sample shows a strong presence of Silicon (Si) alongside Carbon (C). These variations in elemental composition, as highlighted by the EDS analysis, suggest that the observed regions within the samples represent different phases or materials.
Humidity and Temperature:
The temperatures and relative humidity levels for each respective groups showed overall consistency throughout the experimental period.
Effects of Illumination (Dark vs. Light) in Samples:
For Model resin across T1 to T3, the low temperature group consistently demonstrated significant dimensional discrepancies. Meanwhile, ambient temperature conditions at T1 showed non-significant differences, whereas high temperature yielded a significant mean difference in the mean RMS discrepancy. At T2, mean RMS discrepancy for ambient temperature group remained non-significant, contrasting with the high temperature conditions, which maintained statistical significance. At T3, samples in ambient temperature group continued to show non-significant differences, while high temperatures showed a significant difference. For Draft resin at T1, low temperature continued to demonstrate a significant effect. Ambient temperature once again showed non-significant differences, while high temperature exhibited a significant mean difference. For T2, the condition of low temperature reflected a significant influence. Additionally, the ambient temperature group displayed a significant contrast, while high temperature showed a notable mean difference in the mean RMS discrepancy. At T3, low temperature Draft resin in Dark settings maintained the surface stability more significance compared to light settings. As in previous points, ambient temperature yielded significant differences. However, in high temperature conditions, the mean difference in RMS discrepancy was non-significant.
Temperature Contrast Effects Under Varying Illumination at Time Point T3:
Model resin under dark conditions at T3, significant differences were observed regarding temperature conditions. The comparison between low vs. ambient temperatures yielded an significant difference in the mean RMS discrepancy. Similarly, the difference in mean RMS discrepancy for the comparison between low vs. high temperatures was also significant. Also, the ambient vs. high temperature contrast yielded a statistically significant mean difference. Under light illumination, the ambient vs. high temperature contrast yielded a statistically significant mean difference. Additionally, the low vs. ambient temperature comparison demonstrated statistical significance. The low vs. high temperature comparison showed a significant mean difference. Draft resin in the assessment of draft resin under dark conditions at T3, notable differences were observed in dimensional stability based on temperature. The low vs. high temperature contrast exhibited a significant mean difference. Furthermore, the ambient vs high temperature comparison yielded a significant

mean difference. The comparison of low vs. ambient temperatures yielded a modest but significant difference in the dimensional stability of models between these conditions. Under light illumination, the low vs. ambient temperature comparison resulted in a significant difference in the mean RMS discrepancy. The ambient vs. high temperature contrast yielded a highly significant difference. Additionally, the low vs. high temperature comparison indicated a significant difference in RMS discrepancy.
Contrast Between Model and Draft Resin Dimensional Stability Under Varying Temperature and Illumination:
At T1 under dark conditions, in ambient and low temperatures, the difference was significant. However, at high temperatures, the estimated difference was not statistically significant. Switching to light illumination, at low and ambient temperatures at T1, the contrast yielded a significant difference. Conversely, at high temperatures, the estimated difference in mean RMS discrepancy was not statistically significant. At T2 for low and ambient temperatures under dark illumination, the estimated difference in mean RMS discrepancy was statistically significant. Under high-temperature conditions and dark conditions comparison yielded a not statistically significant difference. Under light illumination at low, ambient and high temperatures, a significant difference in the mean RMS discrepancy was noted. At T3 for dark illumination at ambient and high temperatures, the difference in mean RMS discrepancy was significant. Under dark condition at low temperatures, the estimated difference in mean RMS discrepancy was not statistically significant. In contrast to dark settings, under light illumination at low temperatures, the difference in RMS on average was significant. Similarly, the light illumination at ambient temperatures yielded a mean difference in mean RMS showing statistical significance. Under light illumination at high temperatures, the difference in mean RMS discrepancy remained statistically significant.
Temporal Contrast Effects on Resin Dimensional Stability Under Varying Illumination:
Temporal contrast analysis revealed that dimensional stability of both Model and Draft Resins varied across illumination and temperature conditions. Under low temperatures in the dark, most timepoint comparisons showed significant differences, especially between T0 and T3. Light exposure altered these trends, with some early significant differences followed by plateauing effects. At ambient temperature, dark conditions generally resulted in progressive significant discrepancies, while light exposure further amplified them. In high temperatures, early timepoint contrasts were often significant in the dark, but many comparisons under light showed minimal or non-significant changes. Draft Resin followed a similar pattern, with low and ambient temperatures in both lighting conditions showing more pronounced changes over time, whereas high temperature and light exposure produced fewer significant differences. These findings highlight the complex interactions between time, storage conditions, and illumination on resin dimensional stability.
Conclusions:
In conclusion, the results of this study advance our understanding of the interplay between temperature, illumination, and their effect on dimensional stability of 3D printed models in orthodontics. Both resins analyzed demonstrated satisfactory dimensional stability from a clinical perspective. Storage conditions involving dark conditions at low temperatures proved to be the most stable. Importantly, there appears to be no clinically significant difference between the Model and Draft Resins, allowing clinicians to confidently utilize the faster-printed Draft Resin without compromising clinical outcomes. These findings underscore the importance of careful resin selection and consideration of storage environments to ensure optimal clinical outcomes. Ultimately, this research emphasizes the need to account for the interactions between material properties and environmental factors in orthodontic practice, with the aim of continuously enhancing patient care.

Were the original, specific aims of the proposal realized?*

The original specific aims were realized. Our results suggest both Model and Draft Resins have satisfactory dimensional stability, particularly under dark, low-temperature storage conditions. Importantly, clinicians can confidently use the faster-printed Draft Resin without compromising clinical outcomes.

Were the results published?*

No

Have the results of this proposal been presented?*
Yes

To what extent have you used, or how do you intend to use, AAOF funding to further your career?*
AAOF funding enabled me to complete my Master's thesis in Orthodontics and laid a solid groundwork for my research career.

Accounting: Were there any leftover funds?*
$4,041.86

Not Published

Are there plans to publish? If not, why not?*
The thesis has been successfully defended and is submitted to the Department of Orthodontics, University at Buffalo School of Dental Medicine. The manuscript is currently under preparation for publication in a peerreviewed
journal.

Presented

Please list titles, author or co-authors of these presentation/s, year and locations:*
1. Long-term Stability of 3D Printed Orthodontic Models Under Various Storage Conditions: An In-Vitro Study; University at Buffalo Student Research Day 2025 (Buffalo, NY)
2.Long-term Stability of 3D Printed Orthodontic Models Under Various Storage Conditions; American Academy of Orthodontics Annual conference 2025 (Philadelphia, PA)
3. Durability of 3D Orthodontic Models: Effects of Time and Storage ; AADOCR/CADR Annual Meeting 2025 (New York, NY)
Alaa Abdullah, BDS; MS, Asia Allen, BS; Isabella Ortega, BS; William Tanberg, MS; Steven Makowka, MS; Ashish Gurav, DMD, PhD

Was AAOF support acknowledged?

If so, please describe:

AAOF support was recognized both verbally and in writing during all the poster presentations and during thesis defense.

Internal Review

Reviewer comments

The original aims of the proposal were realized. The project resulted in 3 presentations. A manuscript is currently being prepared and will be submitted to a scientific journal.

Reviewer Status*

Approved

File Attachment Summary

Applicant File Uploads

- Abdullah, Alaa 2024 RAA figures & tables.pdf

Figures:

Figure 1: Flow chart for Storage Conditions for 3D Printed Materials

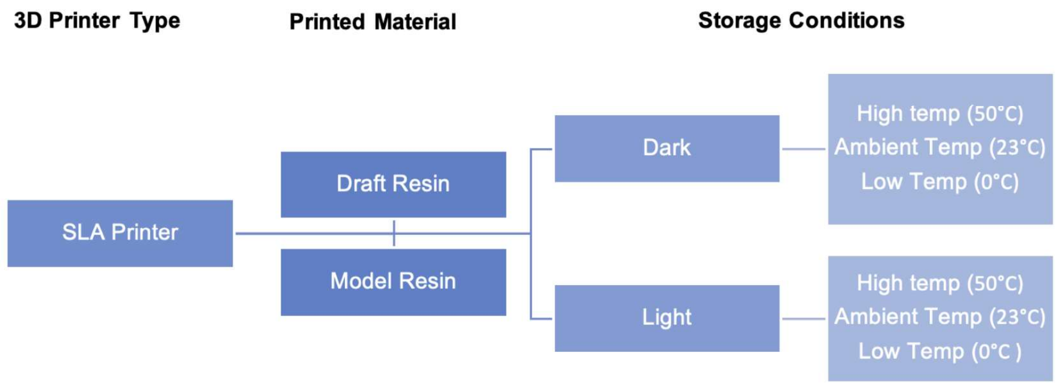


Figure 2: Arrangement of STL Models and Calibration Cube on the Build Platform Using PreForm Software, with the Occlusal Plane Parallel to the Platform.

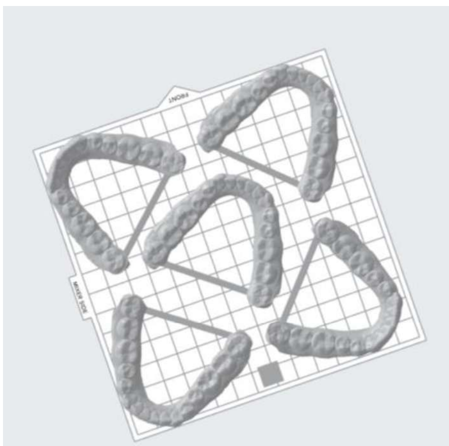


Figure 3: Color Map Depicting Quantified Disparities between Tested scan and Reference Model. Deviations Reported in Millimeters. Positive Deviations (Yellow and Red) Indicate Areas Exceeding Reference Dimensions, Negative Deviations (Blue) Show Reduced Areas, and Green Areas Reflect Proper Surface Alignment Within the Tolerance Threshold of 0.0 mm.

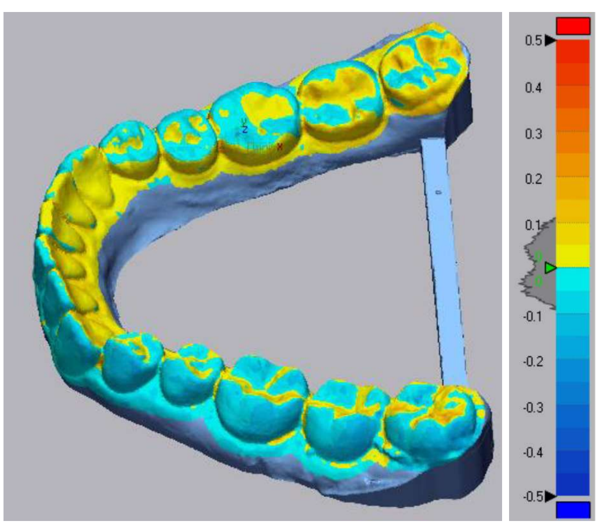


Figure 4. FTIR Spectrum of Draft Resin. The x-axis represents wavenumber (cm-1), and the y-axis represents transmittance (%T).

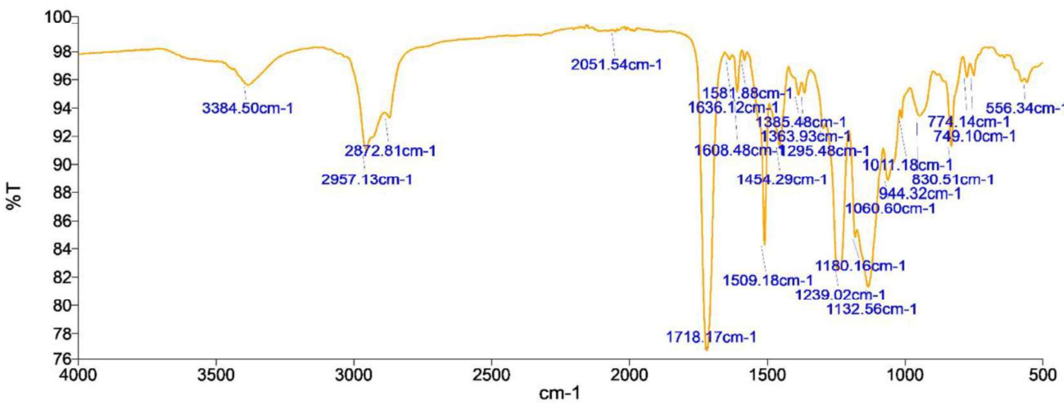


Figure 5. FTIR Spectrum of Model Resin. The x-axis represents wavenumber (cm-1), and the y-axis represents transmittance (%T).

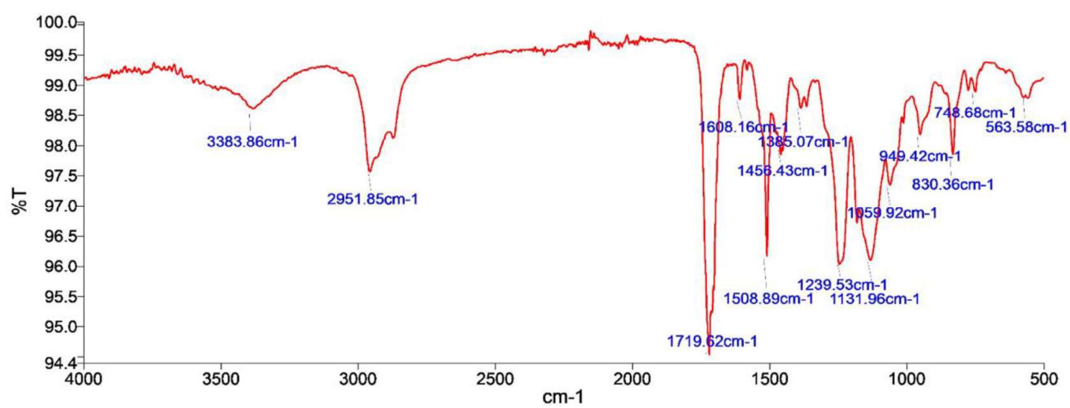


Figure 6: SEM Micrograph of Model Resin Sample (250x Magnification)

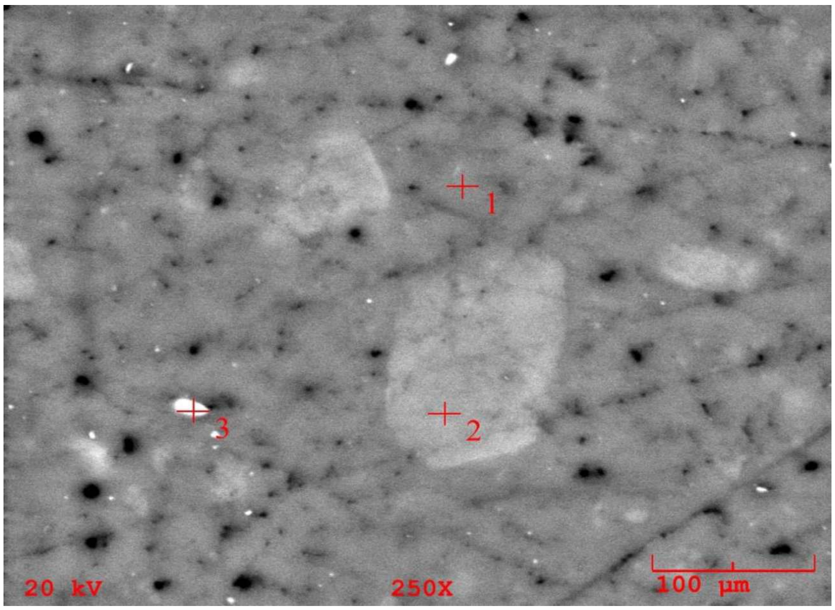


Figure 7: EDS Spectrum representing point 1 from the SEM Micrograph for Model Resin

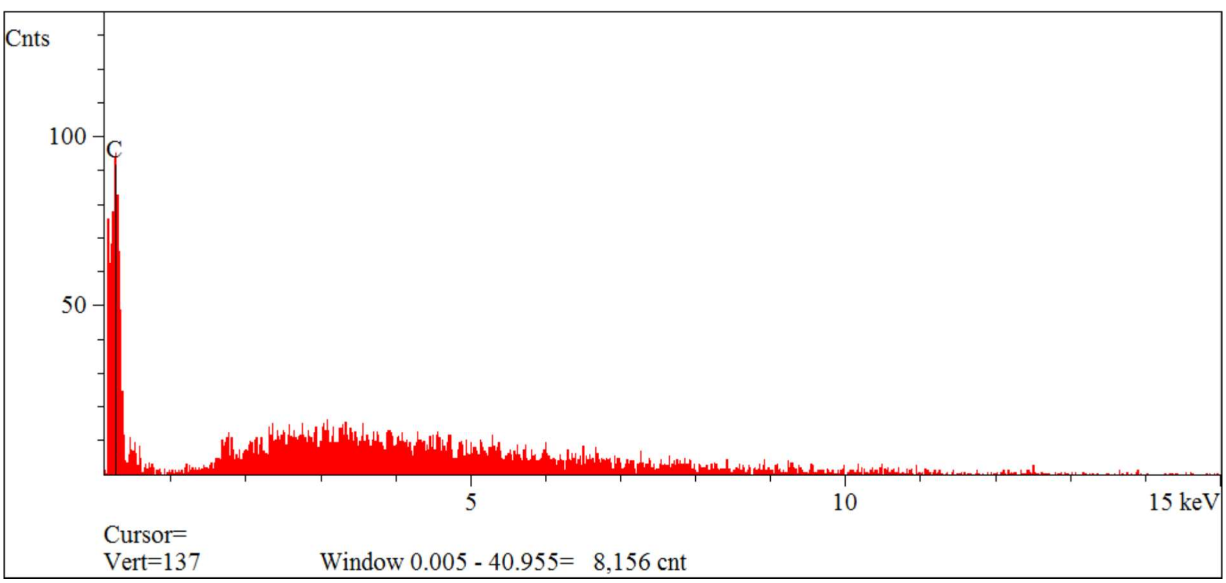


Figure 8: EDS Spectrum representing point 2 from the SEM Micrograph for Model Resin

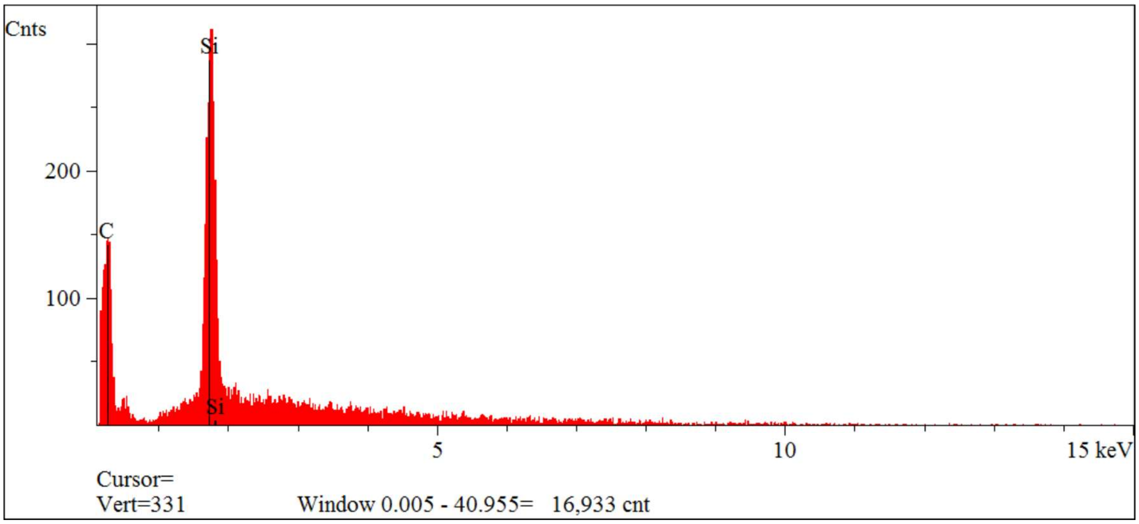


Figure 9: SEM Micrograph of Draft Resin Sample (1kX Magnification)

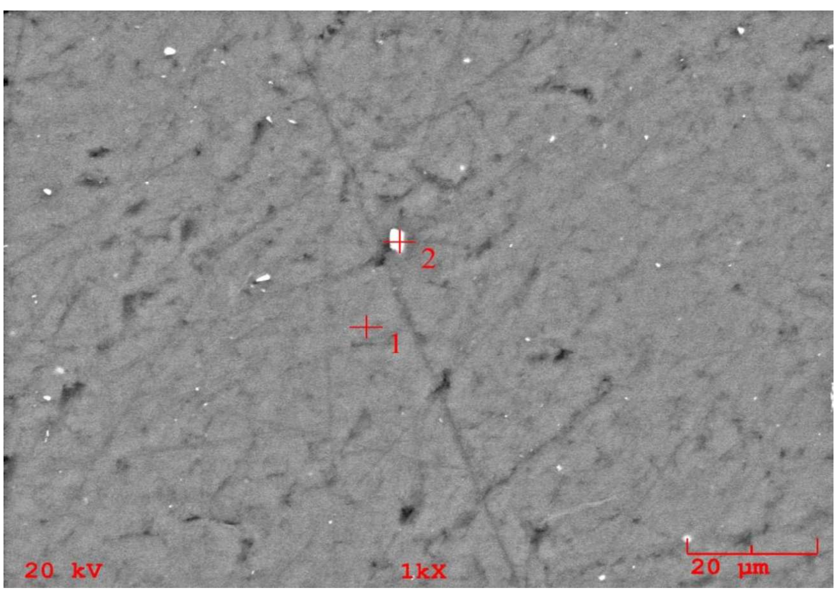


Figure 10: EDS Spectrum representing point 1 from the SEM Micrograph Draft Resin

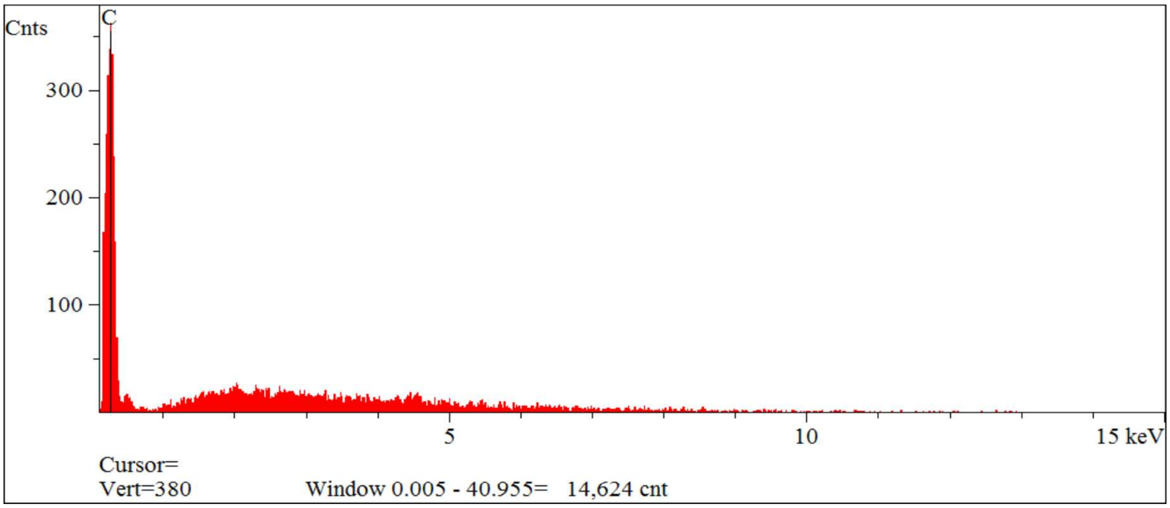


Figure 11: EDS Spectrum representing point 2 from the SEM Micrograph for Draft Resin

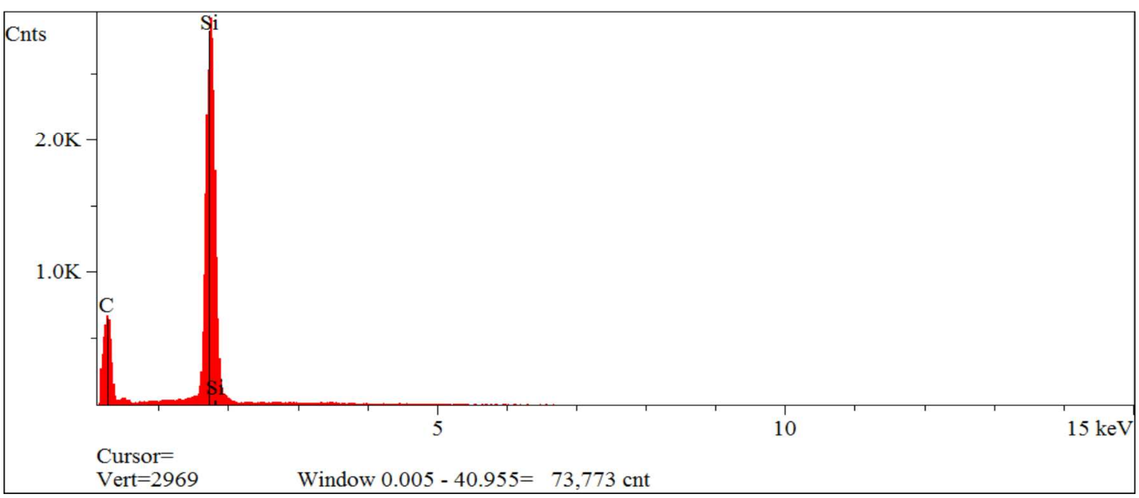


Figure 12: Comparison of RMS (mm) discrepancy in mm under Dark and Light illumination for 'Model' and 'Draft' resins, showing the effect of time (T0-T3) at different temperatures (Low, Ambient, High).

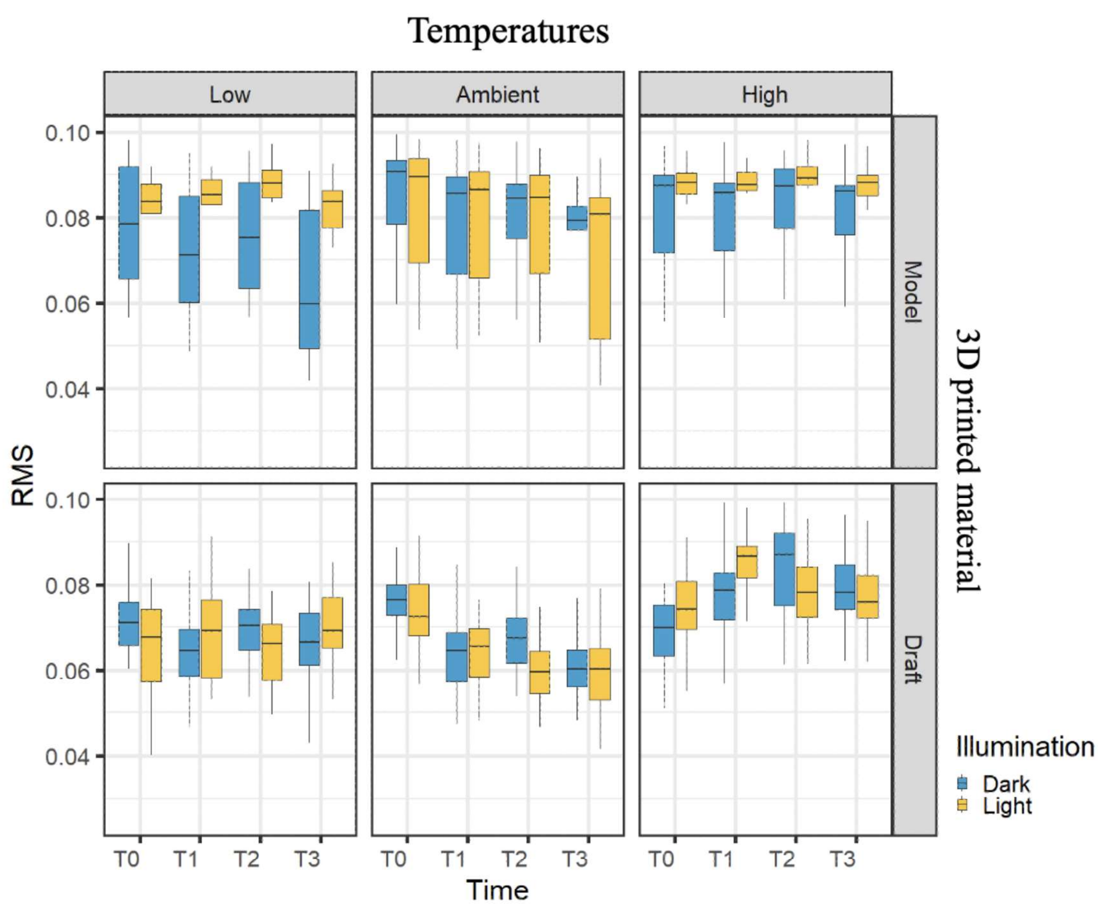


Figure 13: Comparison of RMS (mm) discrepancy in mm between 'Model' and 'Draft' conditions, illustrating the effect of time (T0-T3) on RMS (mm) at different temperatures (Low, Ambient, High) under Dark and Light illumination.

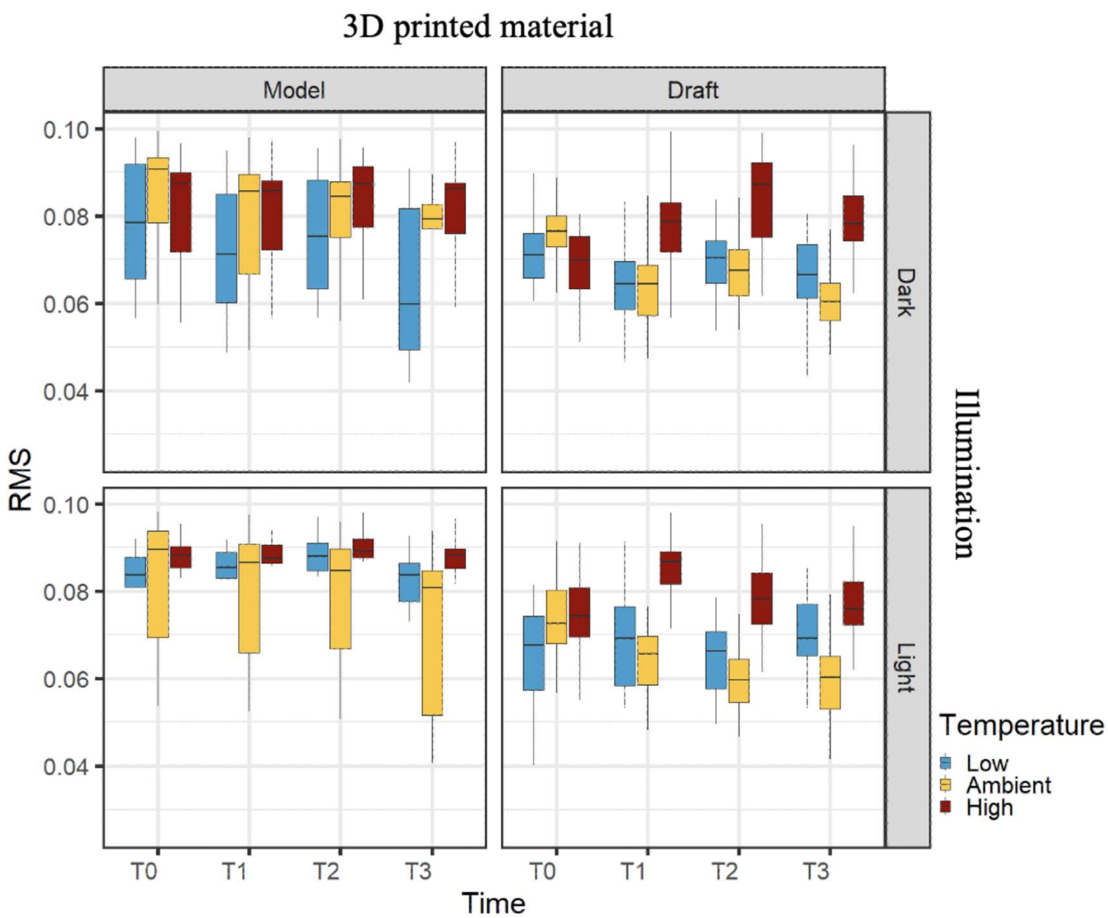


Figure 14: Comparison of RMS (mm) discrepancy in mm between 'Model' and 'Draft' resins, showing the effect of time (T0-T3) at different temperatures (Low, Ambient, High) under Dark and Light illumination

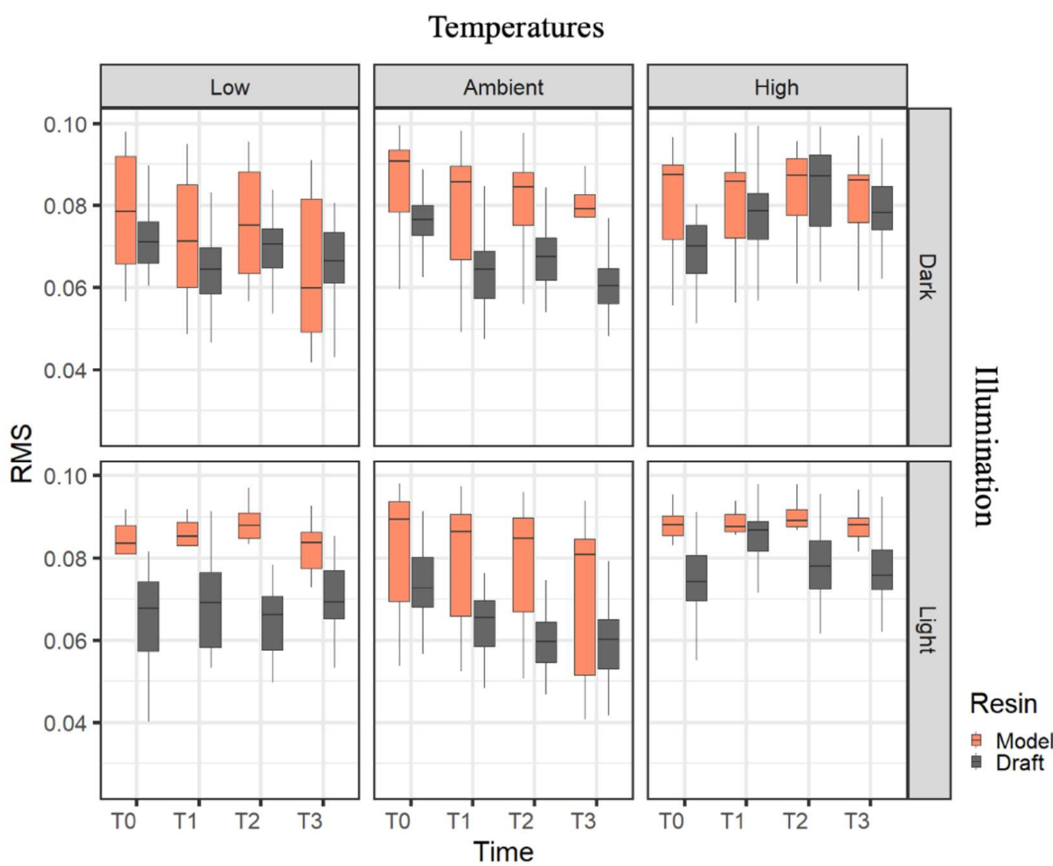
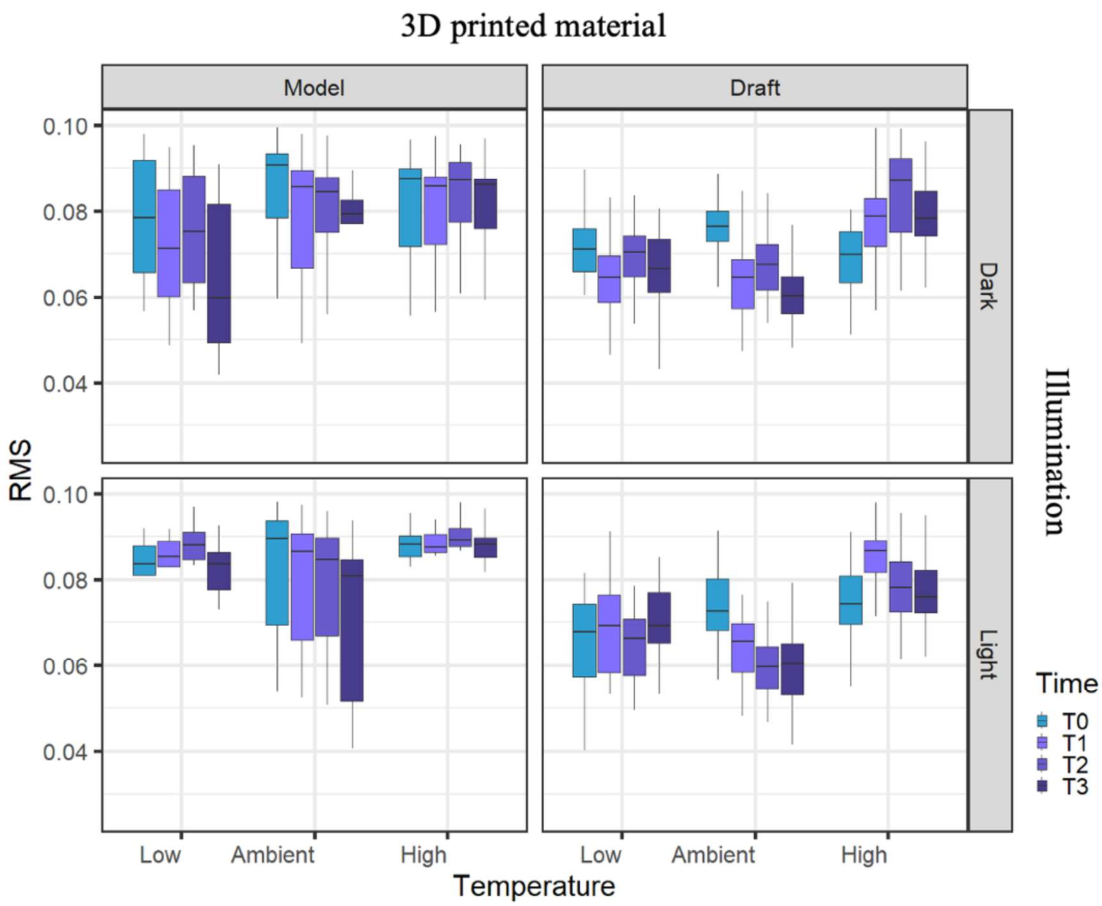


Figure 15: Comparison of RMS (mm) discrepancy in mm between 'Model' and 'Draft' material, showing the effect of temperature (Low, Ambient, High) and time (T0-T3) under Dark and Light illumination.



Tables:

Table 1: FTIR Peak Identification and Transmittance Values of Draft Resin specimen

Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)
1	3384.5	95.65	2	2957.13	91.1	3	2872.81	93.32
4	2051.54	99.44	5	1718.17	76.8	6	1636.12	97.48
7	1608.48	95.14	8	1581.88	97.41	9	1509.18	84.29
10	1454.29	91.35	11	1385.48	94.93	12	1363.93	95.08
13	1295.48	92.57	14	1239.02	82.53	15	1180.16	84.86
16	1132.56	81.32	17	1060.6	88.87	18	1011.18	93.33
19	944.32	93.47	20	830.51	91.27	21	774.14	96.23

Table 2: FTIR Peak Identification and Transmittance Values of Model Resin specimen

Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)	Peak No.	X (cm^{-1})	Y (%T)
1	3384.11	98.19	2	2950.02	96.55	3	1719.01	91.21
4	1608.31	98.12	5	1508.92	94.01	6	1455.38	96.76
7	1385.48	97.93	8	1238.64	93.71	9	1132.06	93.61
10	1059.95	95.72	11	946.54	97.45	12	830.41	96.63
13	773.97	98.37	14	749.01	98.41	15	563.46	98.25

Table. 3: Contrast Between Model and Draft Resin Dimensional Stability Under Varying Temperature and Illumination at all time points.

Condition	Dark condition	Light Illumination
Low Temperature	T1: +DR	T1: +++DR
	T2: +DR	T2: +++DR
	T3: X	T3: +++DR
Ambient Temperature	T1: +++DR	T1: +++DR
	T2: +++DR	T2: +++DR
	T3: +++DR	T3: +++DR
High Temperature	T1: X	T1: X
	T2: X	T2: +DR
	T3: +DR	T3: +DR

+: Significant difference in mean RMS (mm) discrepancy favoring the stated resin material.
+++: Higher significance level than 0.007.
DR: Draft Resin
X: No significant difference between the two materials.
MR: Model Resin

IX Appendix:

Storage Protocols for 3D Printed Resins

Model Resin Storage Protocol

- Store at controlled temperatures between 6.0°C (low) and 25.4°C (ambient) to maintain optimal dimensional stability and prevent degradation.
- Avoid high-temperature environments above 28.4°C, which can adversely affect the integrity of the material.
- Maintain humidity levels between 9.6% and 27.4% RH, as stable humidity is critical for preserving material quality.
- Limit storage exposure to light, particularly in high-temperature conditions, to prevent degradation.
- Use opaque containers or covers to shield against light exposure during prolonged storage.

Draft Resin Storage Protocol

- Store at low (6.0°C) or ambient (25.4°C) temperatures to preserve dimensional stability, as high temperatures compromise material efficacy.
- Aim for stable humidity levels ideally around 9.8% RH to minimize impacts on dimensional stability.
- Protect draft resin from light exposure during storage, especially when stored at higher temperatures, to mitigate degradation effects.

By following these tailored storage protocols, clinicians and manufacturers can preserve the quality and dimensional stability of both model and draft resins, ensuring their effectiveness in various applications.