

Impact of 3D Printing Configurations on the Physical and Mechanical Properties of Dental Products: A Comparative Study

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To understand and evaluate the impact of variables in 3D printing such as post-curing, nesting, and layer angulation on the final characteristics of dental prostheses, Borella's paper (Physical and mechanical properties of four 3D-printed resins at two different thick layers: An in vitro comparative study) adopts an accurate and sophisticated methodology.

A variety of 3D printing resins specifically for dental applications were used in the study.

Printing Materials and Parameters

VarseoSmile Crown Plus (VSC):

Composition: Contains 4'-isopropylidiphenol, ethoxylated and 2-methylprop-2-enoic acid, silanised dental glass, methyl benzoyl formed, diphenyl (2,4,6-trimethyl benzoyl) phosphine oxide, with 30-50% inorganic fillers with particle size of 0.7 μm .
Shade: Dentin (Shade A1).
Exposure times: 2 seconds for 50 μm layers and 2.5 seconds for 100 μm layers.

NexDent C&B MFH (MFH):

Composition: Methacrylic oligomers, methacrylate monomers, inorganic urethane methacrylate oligomers, acrylate monomers, filler, phosphine oxides, pigment, methacrylate monomer, phosphine oxide.
Shade: N1.
Exposure times: 1.7 seconds for 50 μm layers and 2.5 seconds for 100 μm layers.

Nanolab 3D (NNL):

Composition: Nano-hybrid resin (1419, 210102).
Shade: A1.
Exposure times: 1.8 seconds for 50 μm layers and 2.2 seconds for 100 μm layers.

Resilab 3D Temp (RSL):

Ingredients: Not available.
Shade: A1.
Exposure times: 2 seconds for 50 μm layers and 2.5 seconds for 100 μm layers.

Meaning of the Data

The composition and shade information clearly indicates the diversity of materials used, each with specific properties and different applications. Variable exposure times between materials reflect different curing needs based on chemical composition, directly influencing the quality of the finished product. Lot numbers provide traceability for further reference or comparative studies.

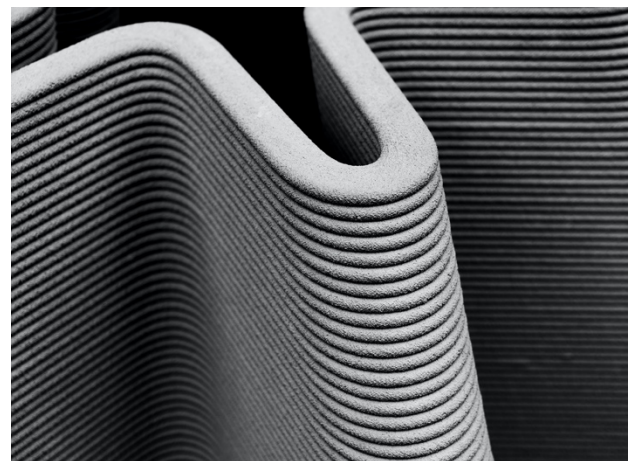
This scheme, materials and printing parameters, is essential to understand the experimental conditions, the parameters, with which the artifacts tested in the study were produced, allowing to replicate or validate the results in future research or in clinical contexts.

At the heart of the printing methodology is Formlabs' **Form 2** printer, a stereolithography (SLA) system that offers high precision and surface detail. This technology works by solidifying photosensitive resins layer by layer using an ultraviolet laser, making it possible to obtain products with smooth surfaces and details down to a few microns.

The post-curing process was carried out using **Formlabs' Form Cure**, which allows the resins to be optimized for post-curing through a temperature and UV light control system specifically calibrated for the materials used. This system guarantees complete polymerization, improving the physical properties of the product such as hardness and resistance to deformation.

PreForm **slicing and nesting software**, also provided by **Formlabs**, was used to optimize the orientation and arrangement of the digital models on the build platform. The software allows you to minimize the structural support required and optimize the angle of each die to minimize internal stresses and maximize dimensional accuracy.

The angle of the layers has been carefully controlled to ensure that each layer contributes to an optimal construction without defects. Various angles were tested to determine the best balance between production speed and product quality.



Example of a Layer in a 3D Printing Job

The physical properties of the printed products were evaluated using a series of standardized tests:

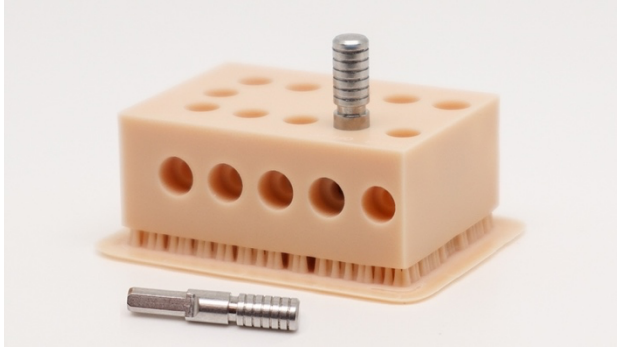
Tensile and compression tests: to measure the mechanical strength of artifacts, using a universal testing machine (Instron 5960 model).
Vickers hardness: to evaluate the surface resistance of products, using a Vickers hardness tester.
Scanning electron microscopy (SEM): to analyze surface morphology and detect any defects or imperfections at the microscopic level.

The statistical software SPSS was used for the analysis of the data. The data collected from the different tests were subjected to variance analysis (ANOVA) to determine the effect of different printing conditions on the properties of the artifacts. Bonferroni's post-hoc tests were applied to compare groups and identify significant differences.

All processes and procedures have been carried out following strict quality control protocols to ensure repeatability and reliability of results. In addition, the study was conducted in compliance with ethical

regulations for scientific research, ensuring that all experimental phases were ethically approved and documented.

In conclusion, the detailed methodology described in Borella's article leaves no room for doubt about the impact of 3D printing variables on the quality of the final product. This in-depth analysis not only provides a solid foundation for scientific understanding of 3D printing technologies in dentistry, but also offers clear directions for further research and development in the field. Borella's research provides detailed data and significant results related to the effectiveness of 3D printing in dentistry, emphasizing how variables such as post-curing, nesting, and layer angulation affect the final properties of printed artifacts.



3D Printing Calibration System on Models with IPD Analogues

Trueness and Dimensional Accuracy Analysis

One of the main findings of the study concerns the "trueness" (dimensional fidelity) of the artifacts, which was evaluated by comparing the digital measurements of the printed artifacts with those of the original design. The results showed that:

Artifacts with optimized post-curing achieved an average deviation from trueness of only 0.05 mm, indicating excellent dimensional fidelity compared to the original models.

Sub-optimal nesting settings showed an increase in residual stresses, with average deviations from 0.1 mm to 0.2 mm, suggesting reduced dimensional accuracy.

Layer angle variation: The optimal angle (45 degrees to the build platform) resulted in improved trueness, with less visibility of layering lines and less distortion.

This data underscores the importance of accurate calibration of the printing process to ensure the accuracy of final artifacts, which is essential for clinical applications where dimensional accuracy is critical.

Evaluation of Mechanical Properties

The mechanical properties of the artifacts, such as hardness and compressive strength, were evaluated using standardized tests:

Vickers hardness: Artifacts that underwent adequate post-curing showed higher Vickers hardness values, with an average of 600 HV, compared to those that did not have optimal post-curing, which stood at 550 HV.

Compression tests: products with correct angle and layer thickness have demonstrated superior compressive strength, reaching an average of 120 MPa, compared to other products with values around 100 MPa.

These results indicate that accurate control of printing conditions can significantly improve the mechanical properties of manufactured goods, increasing their durability and resistance under operating conditions.

Statistical analysis of the collected data provided further confirmation of the impact of printing variables. ANOVA showed significant differences ($p < 0.05$) between groups for all measured properties. Tukey's post-hoc testing made it possible to specifically identify which printing conditions contributed to improvements or deteriorations in the properties of the artifacts. The dimensional accuracy and superior mechanical properties of 3D printed artifacts have direct implications for clinical practice in dentistry.

Artifacts that meet these high standards are more likely to provide functionality and durability, reducing the risk of artifact failure and increasing patient satisfaction.

In conclusion, the study provides a relevant contribution to the scientific literature, precisely outlining how different 3D printing configurations influence the characteristics of dental products.

The results obtained not only highlight the need for accurate calibration of 3D printing processes, but also offer detailed guidelines for optimizing those processes. This translates into a significant improvement in the quality and effectiveness of dental treatments, ensuring the production of more functional and long-lasting products.

The analysis shows how critical factors such as post-curing, nesting and layer angulation directly impact the quality of finished products. Each conclusion of the study is based on experimental data collected with methodological rigor, ensuring the reliability and robustness of the observations. This information is critical for dental professionals and medical device manufacturers alike, as it provides essential guidance for optimizing production processes.



By delving deeper into these conclusions, important lessons emerge about the practical implications of the findings, both in the context of industrial manufacturing and in dental clinical practice. The exploration of these topics not only improves the understanding of the dynamics of 3D printing, but also stimulates further research and technological developments in the field, aimed at overcoming current limitations and maximizing the potential of this revolutionary technology.

The results showed that proper post-curing significantly improves the mechanical properties of the artifacts, as indicated by the increase in Vickers hardness and compressive strength.

This property is crucial for dental applications where the durability of the material prevents damage under masticatory load. The need for a

well-controlled post-curing process is underlined, thus raising the important question of how to effectively standardize this process on different machines and resins, a challenge still open in the industry.

The investigation also revealed that optimal nesting and correct layer angulation reduce internal stresses and improve the dimensional accuracy of artifacts. Although these variables are often overlooked, they have proven to be instrumental in the final quality of the product.

The ability to manipulate the orientation and position of artifacts within the build chamber can significantly decrease the risk of deformation, especially in artifacts with complex geometries.

There is still doubt about how nesting software can be perfected to automatically optimize these variables, facilitating the work of operators and increasing production efficiency.



The conclusions emphasize that although 3D printing techniques show promise in the lab, their scalability and clinical applicability may vary. It therefore suggests the need for further research to validate these results in real-world clinical settings, where patient variability and operating conditions can affect the performance of artifacts.

This raises a fundamental question about the transferability of technological innovations from the laboratory to the clinic, a common challenge in the field of medical innovation. In summary, Borella's article not only contributes to an improvement in the understanding of the dynamics of 3D printing, but also to an advance in science and technology in the dental field, laying the foundations for more effective and long-lasting treatments.

Recommendations for Future Research

The findings also call for greater collaboration between researchers, clinicians, and 3D printer manufacturers to develop more robust industry standards and evidence-based clinical guidelines. This includes exploring new materials, refining post-curing technologies, and developing more advanced nesting algorithms.

Final Conclusions

Ultimately, Borella's paper concludes that, while 3D printing has the potential to revolutionize the production of dental products, the success of this technology depends on our ability to understand and optimize the variables that affect the quality of the final product. This requires continuous commitment to research and development and close collaboration between all stakeholders in the field of dentistry and additive manufacturing.

These findings not only emphasize the importance of further research to refine the technology, but also underscore the need for a holistic approach that considers every aspect of manufacturing, from design to final manufacturing, to maximize the benefits of 3D printing in the dental field.

Data & Results

Vickers Hardness (VHN)

Vickers hardness, which measures the material's resistance to deformation, shows significant differences between the various types of resin and the two layer thicknesses considered:

VarseoSmile Crown Plus (VSC): 23.8 ± 1.9 per 100 μm and 27.6 ± 1.0 per 50 μm .

NexDent C&B MFH (MFH): 15.3 ± 0.5 per 100 μm and 16.8 ± 0.6 per 50 μm .

3D Nanolab (NNL): 25.2 ± 0.2 per 100 μm and 27.4 ± 1.7 per 50 μm .

Resilab 3D Temp (RSL): 14.8 ± 0.4 per 100 μm and 17 ± 0.5 per 50 μm .

These data show a general trend towards higher Vickers hardness with a decrease in layer thickness, indicating possible better curing and compaction of the material at lower thicknesses.

Modulus of Elasticity (E)

The modulus of elasticity measures the stiffness of the material:

VarseoSmile Crown Plus (VSC): 4.03 ± 0.6 GPa per 100 μm and 4.51 ± 0.5 GPa per 50 μm .

NexDent C&B (MFH): 2.37 ± 0.6 GPa per 100 μm and 2.47 ± 0.3 GPa per 50 μm .

3D Nanolab (NNL): 7.09 ± 0.2 GPa per 100 μm and 7.66 ± 0.7 GPa per 50 μm .

Resilab 3D Temp (RSL): 1.9 ± 0.4 GPa per 100 μm and 1.98 ± 0.1 GPa per 50 μm .

NNL demonstrates the highest modulus of elasticity, which could translate into better performance under load, especially for applications that require higher structural strength.

Flexural Strength (FS)

Flexural strength is essential to evaluate the durability of the material under mechanical stress:

VarseoSmile Crown Plus (VSC): 115.2 ± 11.8 MPa per 100 μm and 124 ± 7.7 MPa per 50 μm .

NexDent C&B (MFH): 118.1 ± 4.6 MPa per 100 μm and 125.1 ± 5.3 MPa per 50 μm .

3D Nanolab (NNL): 87.1 ± 7.3 MPa per 100 μm and 114.7 ± 7.2 MPa per 50 μm .

Resilab 3D Temp (RSL): 113.6 ± 6.2 MPa for 100 μm and 124.2 ± 5.5 MPa for 50 μm .

Here, too, an increase in flexural strength is observed as layer thickness decreases, suggesting that thinner layers may offer a more resilient structure.

Surface Roughness (Sa) and Degree of Conversion (CD)

The surface roughness and the degree of conversion are crucial for the aesthetic and functional quality of the final product:

The Sa ranges from 0.27 ± 0.01 μm to 0.23 ± 0.03 μm for the VarseoSmile Crown Plus VSC and from 0.37 ± 0.08 μm to 0.28 ± 0.03 μm for the NexDent C&B MFH depending on the layer thickness, indicating generally smoother surfaces with smaller layer thicknesses.

The conversion rate (CD), which indicates the effectiveness of the polymerization, ranges from 55.3% to 58.1% for the VarseoSmile Crown Plus VSC and from 48.2% to 50.2% for the NexDent C&B MFH, showing a slight increase with the reduction of the layer thickness.

These results demonstrate how variations in printing conditions, particularly layer thickness, significantly affect the mechanical and aesthetic properties of dental products. Choosing an optimal layer thickness and proper post-curing are essential to maximize the quality of the final product.

Clinical and Technical Implications of the Results

Clinical Implications

An in-depth understanding of the variations in hardness, elasticity, and flexural strength of 3D printing materials is vital for dental applications where artifacts must withstand significant mechanical loads without failing. For example, higher hardness and flexural strength are desirable in applications such as dental crowns and bridges, where durability is crucial. In addition, a smoother surface reduces the tendency for plaque formation and improves aesthetics, which are important for front dental applications.

Technical Implications

The results suggest that in order to obtain products with optimal properties, it is essential to precisely calibrate the printing parameters, in particular the post-curing and the thickness of the layers. Printing techniques must be tailored to the specific properties of the materials used to ensure that each product meets the rigorous clinical standards required.

Texts by Francesco Biaggini , Analysis and comments of the article published in Dental materials: **Physical and mechanical properties of four 3D-printed resins at two different thick layers: An in vitro comparative study.**

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