



## Evaluating 3D Printed Dental Models of Varying Wall Thicknesses for Maximizing Cost-Effectiveness & Time Efficiency

Dr. Prachi T. Khatri<sup>1</sup>, Dr. Neeraj E. Kolge<sup>2</sup>, Dr. Lishoy W. Rodrigues<sup>3</sup>, Dr. Mugdha S. Raut<sup>4</sup>, Dr. Gaury A. Vajarekar<sup>5</sup>, Dr. Smriti S. Tiwari<sup>6</sup>, Dr. Shubham B. Bhavane<sup>7</sup>, Maithilee V. Gavali<sup>8</sup>

<sup>1</sup>B.D.S., MGM Dental College & Hospital, Navi Mumbai, Maharashtra, 410209, India, Dental Trainee at Dental Square, Andheri, Mumbai, 400069, India.

<sup>2</sup>BDS, MDS, FWFO, FPFA, Assistant Professor, Department of Orthodontics & Dentofacial Orthopaedics, MGM Dental College & Hospital, Navi Mumbai, Maharashtra, 410209. Ph.D. Scholar, Department of Orthodontics & Dentofacial Orthopaedics, Government Dental College & Hospital, Nagpur. Honorary Dental Surgeon, Rotary Club of Bombay.

<sup>3</sup>B.D.S., M.D.S., Ph.D. Scholar (Orthodontics), Fellow of World Federation of Orthodontics (USA), Fellow of Comprehensive Cleft Care, Dip. In Forensic and Medical Jurisprudence, Dip. in Cyber Law, PGDHM. Assistant Professor in the Department of Orthodontics and Dentofacial Orthopedics at Sinhgad Dental College and Hospital, Pune, Maharashtra, 411041, India.

<sup>4</sup>D.M.D (University of Pennsylvania School of Dental Medicine) Philadelphia 19107, USA . B.D.S., M.D.S (Oral and Maxillofacial Pathology) Ex-Assistant Professor Department of Oral Pathology and Microbiology Nair Hospital Dental College Mumbai 400008, India.

<sup>5</sup>B.D.S., M.D.S, (Orthodontics), Orthodontist and General Dentist at Dr. Vajarekar's Multispecialty Dental Clinic and Orthodontic Care Centre. Ghadi House, opp. Homi Bhabha Centre for Science Education, Sion Trombay road, near BARC main gate, Mankhurd, Mumbai 400088, India.

<sup>6</sup>B.D.S., First year M.D.S. (Orthodontics & Dentofacial Orthopaedics), MGM Dental College & Hospital, Navi Mumbai, Maharashtra, 410209.

<sup>7</sup>B.D.S., MGM Dental College & Hospital, Navi Mumbai, Maharashtra, 410209, Dentist at Children's Aid Society, Associate dentist at Vichare Dental Clinic.

<sup>8</sup>Final year student, MGM Dental College & Hospital, Navi Mumbai, Maharashtra, 410209.

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### KEYWORDS

3D printing, cost-effectiveness, dental resin models, printing time, resin wall thickness

### ABSTRACT:

#### Introduction:

The field of dentistry & Orthodontics as well has increasingly adopted 3D printing technology. In Orthodontics it is used to expedite the production of custom made aligners, which provide aesthetic benefits and comfortable patient experience. Traditional methods of sourcing aligners from dental labs/companies is decline as it is costly and time consuming, prompting a shift towards in-office 3D printing for manufacturing of clear aligners.

#### Aim and Objective:

The primary aim of the article is to assess the cost-effectiveness by analyzing resin usage across a range of wall thicknesses and solid models in 3D printing. The secondary aim is to compare the printing time and resin material consumption of horizontal and vertical orientations for varying wall thicknesses and solid models.

#### Materials and Methods:

The study employed a compatible 3D printer in conjunction with standard photopolymer resin material. The models were hollowed and printing parameters were configured using Meshmixer & Chitubox Dental software respectively. A total of 400 models were produced, with 40 models for each specified wall thickness (1mm, 1.25mm, 1.5mm, 1.75mm, 2mm,



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2.25mm, 2.5mm, 2.75mm, 3mm, and solid). Resin consumption (in milliliters) was measured for individual models as well as for monthly production. The study included a comparative analysis of horizontal versus vertical printing orientations. Additionally, a percentage analysis of resin efficiency and the number of models printable per bottle of resin were performed.

### Results:

Findings of our study demonstrate a direct relationship between model wall thickness and resin usage. The resin savings achieved with varying model wall thicknesses compared to a solid model, emphasizing significant material efficiency. Specifically, transitioning from a solid model to one with a wall thickness of 1.00mm results in a 71.2% reduction in resin usage, while a 3.00mm wall thickness model achieves a substantial 16% reduction. These findings underscore the inverse relationship between model wall thickness and resin consumption, offering crucial insights for cost-effective and sustainable 3D printing practices in the dental industry. A comparative analysis of horizontal and vertical printing orientations clarify inherent differences. Horizontal printing takes 86.71 hours to produce 65 solid models, while vertical printing requires 91.65 hours. However, there is no significant difference in the time required for printing models horizontally or vertically, as the time is almost equivalent.

### Conclusion:

The study emphasizes the importance of selecting optimal model wall thicknesses to balance material efficiency and aligner functionality for thermopressing on 3D printed models. It provides actionable insights for dental offices to enhance cost-effectiveness for in-office aligner production through informed material choices and printing strategies, contributing valuable data for effective in office aligner production.

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### Introduction:

The field of dentistry & Orthodontics as well has increasingly adopted 3D printing technology. 3D printing technology, also known as cumulative manufacturing, has surfaced as a transformative force in the dental industry<sup>1</sup>. This technology enables the creation of precise, customized dental models and appliances directly from digital lines, revolutionizing traditional dental practices<sup>2</sup>. The capability to fleetly produce accurate dental models acclimatized to individual case deconstructions enhances individual capabilities, treatment planning, and the fabrication of dental appliances, eventually perfecting patient issues<sup>3</sup>. One of the critical factors driving the acceptance of 3D printing in dentistry is its eventuality to reduce costs and increase effectiveness<sup>4</sup>. Still, despite its advantages, the cost-effectiveness of 3D printing remains a concern for numerous dental practices. The primary charges involved in 3D printing include the cost of the resin material and the functional costs associated with running the 3D printer<sup>5</sup>. Optimizing these costs is essential for dental

conventions to completely work the benefits of 3D printing technology. This study focuses on assessing the cost- effectiveness of 3D printed dental models by assessing the resin material needed and the associated costs for printing models with varying density. Specifically, the exploration examines concave models with density ranging from 1 mm to 3 mm and compares them to solid models. The study aims to give a comprehensive understanding of how different model density impact resin operation and overall printing costs, offering precious insights for dental offices looking to optimize their 3D printing processes. Resin material used in 3D printing are a critical element impacting the quality, continuity, and cost of the printed models. Standard photopolymer resin is a popular choice for dental operations due to its excellent mechanical properties, smooth finish, and trustability. Still, colorful other resins, including tough, flexible, and castable resins, are available for specific dental operations, each with distinct properties and cost charges.



## Aim and objective:

The primary aim of this research is to compare the cost and material efficiency of 3D-printed dental models with different wall thicknesses. The specific objectives are:

1. Assess the cost-effectiveness by analyzing resin usage across a range of wall thicknesses and solid models in 3D printing.
2. Compare the printing time and resin material consumption of horizontal and vertical orientations for varying wall thicknesses and solid models.

The practical applicability of this study lies in its implicit to guide dental practitioners in opting the most cost-effective and material-effective strategies for 3D printing dental models. By furnishing detailed comparisons of resin operation and costs for models with different density. This study aims to support dental offices in making informed opinions that enhance the sustainability and profitable viability of their 3D printing practices irrespective of brand of printed/ resin used.

## Materials and methods:

### Materials:

#### 1. Resin:

**Standard Photopolymer Resin:** (Elegoo, Shenzhen, China)

It cures under UV light, ensuring rapid solidification and precise layering, which are crucial for creating accurate dental appliances. The resin meets stringent biocompatibility standards, ensuring it is safe for intraoral use without causing adverse reactions in patients. Resin material used in 3D printing are a critical element impacting the quality, continuity, and cost of the printed models<sup>6</sup>.

### Equipments:

#### 1. Laptop:

Intel Core i7-13650HX | Speed: 2.6GHz (Base) - 4.9GHz (Max) | 14 Cores | 20 Threads | 24MB Cache

#### 2. 3D Printer:

Saturn 3 12K (Elegoo, Shenzhen, China)

#### 3. Cleaning Unit

#### 4. Curing Unit

#### 5. Software:

Meshmixer Software (Autodesk, San Francisco, California, USofA)

ChituBox Dental Software (V1.0.3, CBD Technology, Shenzhen, China)

## Methods:

The study encompasses the entire workflow, from pre-printing preparations to the actual printing process and subsequent data collection.

### 1. Pre-Printing Preparations

#### a. Model Sectioning and Cutting:

Before printing, the dental models were digitally sectioned and cut using 3D modeling software. This process ensures that the models fit the printer's build volume and facilitates easier handling post-printing.

#### b. Hollowing the Models:

To minimize material usage and reduce printing costs, the models were hollowed using an software called Meshmixer (V3.5) The hollowing process involved creating internal cavities within the models, maintaining structural integrity while significantly lowering the resin volume required for printing.

### 2. Slicing and Printing the Models

ChituBox Dental (V1.0.3) is a popular slicing software used in resin-based 3D printing. It converts 3D models into a format that can be interpreted by the 3D printer, generating the necessary instructions for each layer of the print. It slices 3D models into individual layers, creating a detailed plan for the printer to follow. This process is crucial for ensuring that each layer is printed accurately and adheres to the previous layer. The software automatically generates support structures for overhangs and complex geometries. These supports are essential for maintaining the integrity of the print during the curing process.

#### a. Horizontal Printing:

For horizontal printing, the models were oriented flat on the build plate of the 3D printer. Five models were printed per batch, as this orientation optimizes build plate utilization and ensures stable printing with minimal support structures. The time required for printing five models of varying wall thicknesses was recorded.

#### b. Vertical Printing:

In vertical printing, the models were oriented upright on the build plate. Thirteen models were printed per batch, maximizing the use of vertical space. This orientation,



while allowing more models to be printed simultaneously, required careful calibration to prevent tipping and necessitated additional support structures. The time required for printing thirteen models of varying wall thicknesses was recorded.

### 3. Data Collection

#### a. Resin Usage Calculation:

The amount of photopolymer resin used for printing each model was measured. Resin consumption for models of different wall thicknesses was calculated by weighing the models post-printing and accounting for the density of the resin.

#### b. Cost Analysis:

The cost of resin used was determined based on the resin volume consumed and percentage of resin saved.

#### c. Printing Time Recording:

The time required for printing models of each wall thickness in both horizontal and vertical orientations was recorded. These times were used to compare the efficiency of different orientations and wall thicknesses.

#### d. Monthly Resin Usage:

For a hypothetical scenario, where a dental office prints 400 models per month, the total resin used and the associated costs were calculated. This analysis included both the number of models that can be printed from one bottle of resin and the cost-effectiveness of varying wall thicknesses.

### Results:

The results of the study are summarized in tables and charts detailing resin usage and costs for single models for each wall thickness. A comprehensive analysis highlights the differences in material efficiency and cost-effectiveness across various model wall thicknesses.

### I. Analysis and Implications:

#### a. Resin Usage and Percentage of Resin saved for Single Models (Table No: 1)

The resin usage incrementally increase with the model thickness, ranging from 7.2 ml for a 1 mm thick model to 25 ml for a solid model. This direct correlation between wall thickness and material is critical for planning in clinical settings.

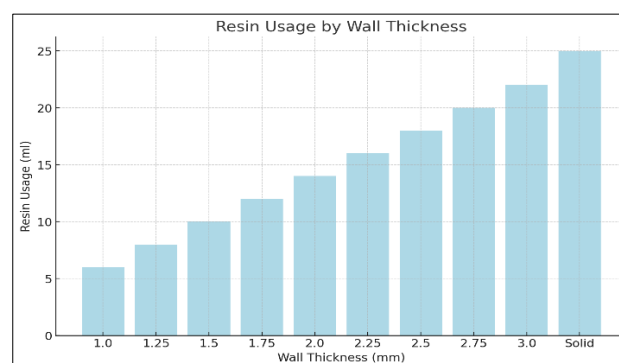
#### b. Monthly Production Resin usage (Table No: 2)

Monthly resin usage vary significantly based on model wall thickness. A clinic producing 400 models per month will spend between 2280 ml resin for 1 mm thick models

and 9870 ml resin for solid models. This variability underscores the need for careful consideration of model wall thickness in routine clinical operations to optimize costs.

Wall Thickness (mm)	Resin Usage (ml)
1.00	7.2
1.25	8.9
1.50	10.6
1.75	12.3
2.00	14
2.25	15.7
2.50	17.4
2.75	18.3
3.00	21
Solid	25

**Table 1:** Resin usage for printing single model



**Figure 1:** Wall thickness (mm) V/S Resin Usage (ml)

Wall Thickness (mm)	Monthly Resin Usage (ml)
1.00	2880
1.25	3560
1.50	4240
1.75	4920
2.00	5600
2.25	6280
2.50	6960
2.75	7320
3.00	8320
Solid	9870

**Table 2:** For dental office printing 400 models per month

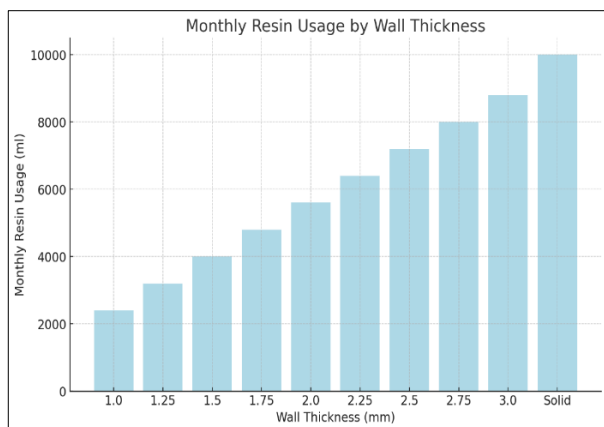


Figure 2: Monthly Resin usage for printing 400 models

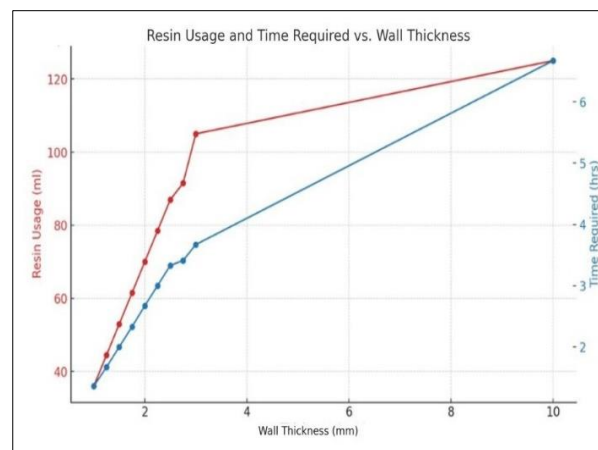


Figure 3: Resin usage (ml) and Time Analysis (hrs) for Horizontal Printing (5 models per batch)

## II. Horizontal vs. Vertical Printing Analysis:

The comparative analysis of horizontal and vertical printing orientations highlights significant differences in resin usage, costs, and time required.

### a. Horizontal Printing (Table No: 3)

Horizontal printing of 1 mm thick models requires 1.33 hours and consumes 36 ml of resin per batch of five models. As wall thickness increases, both time and material usage increase proportionally.

### b. Vertical Printing (Table No: 4)

Vertical printing, which accommodates 13 models per batch, requires 3.8 hours and uses 93.6 ml of resin for 1 mm thick models. This orientation, while more efficient in terms of batch size, results in longer print times due to the increased vertical build height.

Wall Thickness (mm)	Resin Usage (ml)	Time required (hrs)
1.00	93.5	3.80
1.25	115.7	4.75
1.50	137.8	5.50
1.75	159.9	6.33
2.00	182	7.25
2.25	204.1	8.20
2.50	226.2	9.00
2.75	237.9	9.50
3.00	273	10.00
Solid	325	18.33

Table 4: Vertical Printing Resin (ml) and Time Analysis (13 models per batch)

Wall Thickness (mm)	Resin Usage (ml)	Time required (hrs)
1.00	36	1.36
1.25	44.5	1.67
1.50	53	2.00
1.75	61.5	2.33
2.00	70	2.67
2.25	78.5	3.00
2.50	87	3.33
2.75	91.5	3.41
3.00	105	3.67
Solid	125	6.67

Table 3: Horizontal Printing Resin (ml) and Time Analysis (5 models per batch)

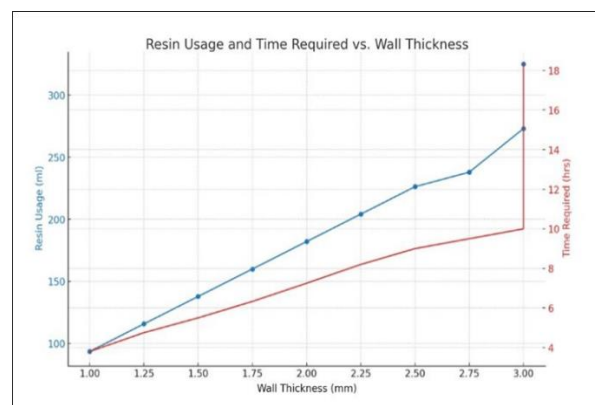


Figure 4: Resin usage (ml) and Time Analysis (hrs) for Vertical Printing (13 models per batch)



To calculate the total time required to print 65 models with varying wall thicknesses using both horizontal and vertical printing orientations, we need to determine the number of batches required and multiply by the time per batch for each wall thickness.

For horizontal printing:

Number of batches required = Total models / Models per batch = 65 / 5 = 13 batches

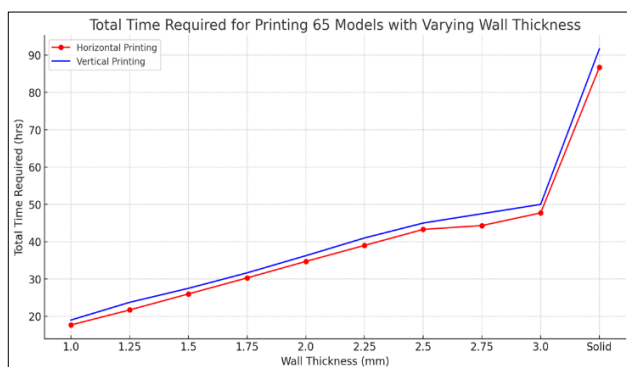
For vertical printing:

Number of batches required = Total models / Models per batch = 65 / 13 = 5 batches

Using the provided data, we calculated the total time required for different wall thicknesses in both horizontal and vertical orientations:

Wall Thickness (mm)	Horizontal Printing time (hrs)	Vertical Printing time (hrs)
1.00	17.68	19.0
1.25	21.71	23.75
1.50	26.0	27.50
1.75	30.29	31.65
2.00	34.71	36.25
2.25	39.0	41.0
2.50	43.29	45.0
2.75	44.33	47.50
3.00	47.71	50.0
Solid	86.71	91.65

**Table 5:** Total time required to print 65 models with varying wall thicknesses using both horizontal and vertical orientations



**Figure 5:** Total time required to print 65 models with varying wall thicknesses using both horizontal and vertical printing orientations

### III. Percentage Analysis and Model Counts per Resin Bottle: (Table No: 6 and 7)

To elucidate the material efficiency, we calculated the percentage of resin used for different wall thicknesses compared to solid models.

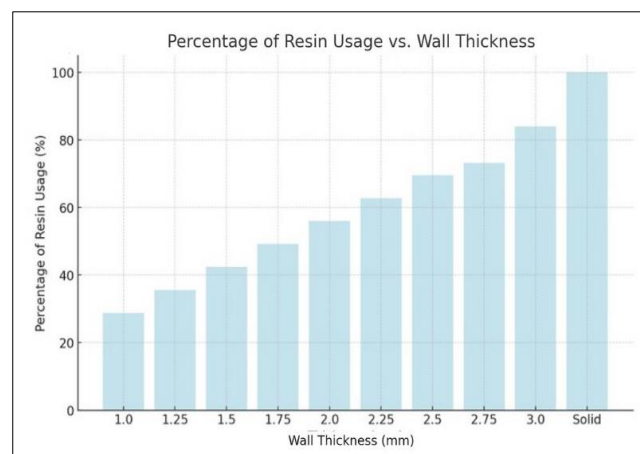
To calculate the percentage of resin used for different model wall thicknesses compared to the solid model, we use the following formula:

$$\text{Percentage}(\%) = \frac{\text{Resin usage for a specific wall thickness}}{\text{Resin usage for a solid model}} \times 100$$

Resin usage for a solid model

Wall Thickness (mm)	Percentage of resin usage (%)	Resin Savings (%)
1.00	28.8	71.2
1.25	35.6	64.4
1.50	42.4	57.6
1.75	49.2	50.8
2.00	56.0	44.0
2.25	62.8	37.2
2.50	69.6	30.4
2.75	73.2	26.8
3.00	84.0	16.0
Solid	100	0

**Table 6:** Percentage of resin model usage

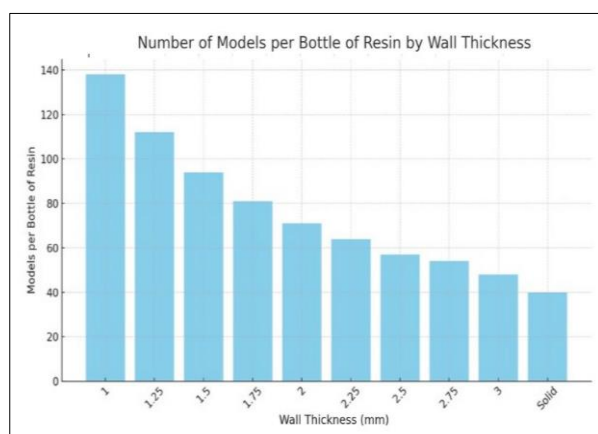


**Figure 6:** Percentage of resin model usage



Wall Thickness (mm)	Models per bottle of resin
1.00	138
1.25	112
1.50	94
1.75	81
2.00	71
2.25	64
2.50	57
2.75	54
3.00	48
Solid	40

**Table 7:** Models printed per bottle of resin



**Figure 7:** Models printed per bottle of resin

The study's findings are presented through detailed tables and charts illustrating resin consumption for single models across various wall thicknesses. (Table: 1, Figure: 1). The study's findings demonstrate a direct relationship between model wall thickness and resin usage, findings of which are similar to a previously conducted study<sup>7</sup>. It highlights the direct relationship between model wall thicknesses and resin usage, with thinner models costing less per unit but exhibiting higher failure rates, thereby increasing overall expenses. Conversely, thicker models, despite higher initial resin consumption, offer enhanced durability and reduced failure rates. The analysis also emphasizes the efficiency gained from group printing. Monthly production variations (Table: 2, Figure: 2) underscore the financial implications of model wall thickness choices in clinical operations, guiding optimal budget planning. Additionally, the comparison between horizontal and

vertical printing (Table 3&4, Figure: 3&4) orientations reveals distinct trade-offs in resin usage, costs, and time efficiency. Horizontal printing generally offers better surface quality but requires more support material, whereas vertical printing conserves resin but extends print times to almost 3 times due to its additive printing technology. The provided data offers a comparative analysis of the total time required to print 65 models with varying wall thicknesses using both horizontal and vertical printing orientations (Table: 5, Figure: 5). For horizontal printing, which accommodates five models per batch, the total number of batches required is 13. In contrast, vertical printing, accommodating 13 models per batch, requires only five batches. The calculated total printing times across different wall thicknesses elucidate the efficiency trade-offs between the two orientations. For instance, at a wall thickness of 1.00 mm, horizontal printing requires 17.68 hours, whereas vertical printing requires 19.0 hours. As the wall thickness increases, this trend persists, with horizontal printing generally maintaining a slight time advantage for thinner models. However, this advantage diminishes and eventually reverses for thicker models due to the increased vertical build height in vertical printing. At a wall thickness of 3.00 mm, horizontal printing demands 47.71 hours compared to 50.0 hours for vertical printing. Notably, for solid models, the time required converges, with horizontal printing taking 86.71 hours and vertical printing taking 91.65 hours. This analysis underscores the importance of considering both batch size and wall thickness when optimizing 3D printing processes for efficiency. Percentage analysis (Table: 6, Figure: 6) demonstrates the resin efficiency of different model wall thicknesses relative to solid models, highlighting the varying material economies across wall thickness categories. Moreover, the calculation of models printable per bottle of resin (Table: 7, Figure: 7) provides practical insights into resource management and operational scalability in 3D printing for dental applications. These findings contribute valuable data for optimizing cost-effectiveness and operational efficiency in dental 3D printing, crucial for informed decision-making in clinical and educational settings.

#### Discussion:

In this study, we investigated the cost-effectiveness of 3D-printed dental models across a range of wall



thicknesses from 1mm to 3mm, alongside solid models. Our experimental methodology encompassed printing 40 models per wall thickness category and analyzing resin consumption with each 1000ml bottle of resin. The findings revealed substantial variations in material usage and production costs across the wall thickness spectrum.

The cost-effectiveness analysis underscored the advantages of thicker models over solid models which, despite their initial higher resin consumption, offered significant savings over time due to their enhanced structural integrity and reduced incidence of print failures<sup>8</sup>. These models proved particularly beneficial in contexts prioritizing durability and reliability, such as dental education and patient education settings. Optimal wall thicknesses for bulk printing were identified within the 2mm to 3mm range, balancing resin efficiency with dimensional stability to maximize cost-effectiveness without compromising quality.

The comparative analysis of horizontal and vertical printing orientations reveals several critical insights<sup>9</sup>. Horizontal printing, though requiring more support structures and increasing material consumption, yields a superior surface finish and greater stability. Conversely, vertical printing conserves resin and support materials, but it presents challenges related to print stability and layer adhesion, impacting overall print quality and durability. Furthermore, the data indicate significant differences in resin usage and time requirements, with horizontal printing being more time-efficient for smaller batches. These findings underscore the necessity of selecting the appropriate printing orientation based on specific application needs, balancing material costs, print quality, and operational efficiency. In the context of dental models, these considerations are crucial for optimizing cost-effectiveness and achieving the desired clinical outcomes.

Furthermore, our study contributes to the broader discourse on additive manufacturing in dentistry by addressing practical considerations in resin selection and printing methodology. Future research directions could explore alternative resin formulations or hybrid materials capable of offering enhanced mechanical strength without compromising cost-effectiveness, thereby expanding the scope of applications for 3D-printed dental models.

A critical aspect of our research was the systematic evaluation of resin consumption and time effectiveness. By rigorously comparing resin usage across different model wall thicknesses and printing orientations, we provided actionable insights into optimizing operational workflows and resource allocation. These findings hold particular relevance for institutions seeking to integrate 3D printing into their educational or dental practices, where efficient resource management and cost-effectiveness are essential for sustainable implementation.

Additionally, our findings highlight the importance of using standardized procedures for 3D printing in dentistry. Clear guidelines for choosing resin, setting printing parameters, and post-processing methods can reduce variability in print outcomes, ensuring consistent quality across different batches of dental models. This standardization improves reproducibility in educational settings and builds confidence in clinical applications. Accurate and reliable anatomical models are essential for effective treatment planning and patient communication, making standardized procedures crucial for advancing 3D printing technologies in dental practices.

In conclusion, our comprehensive analysis of resin consumption, cost-effectiveness, and printing methodologies provides valuable insights into optimizing 3D printing practices for dental applications. By leveraging the strengths of thicker models and evaluating the impact of printing orientations, we offer practical recommendations for enhancing efficiency, reducing costs, and improving the reliability of 3D-printed dental models. These insights pave the way for future advancements in additive manufacturing technologies, potentially benefiting fields such as personalized medicine and advanced dental prosthetics. Our research highlights the critical impact of model wall thickness on optimizing 3D printing practices for dental applications, particularly for in-office aligner production. By analyzing the interplay between resin usage, cost, and printing efficiency across varying model wall thicknesses, we have identified that thicker models, specifically those ranging from 2mm to 3mm, offer superior benefits. These models demonstrate enhanced durability, reduced failure rates, and greater economic value over time, despite higher initial resin costs. Our findings emphasize the importance of selecting



appropriate model wall thickness to balance production speed with reliability and cost-effectiveness. The study reveals the practical implications of resin selection and printing methodologies for enhancing the feasibility and economic viability of 3D-printed dental models<sup>10</sup>.

The significance of these results lies in their potential to transform 3D printing practices within dental settings. Thicker models, with their improved structural integrity and lower incidence of print failures, contribute to more reliable and durable dental prosthetics and orthodontics. This resilience not only minimizes material wastage and the need for reprints but also supports long-term cost efficiency, making it particularly advantageous for high-volume production environments such as dental clinics and educational institutions. By prioritizing thicker models, practitioners can achieve consistent quality while optimizing resource utilization.

#### Limitations:

Future research should aim to address the limitations identified in this study by incorporating a broader range of resin materials and 3D printer models to enhance the generalizability of the findings. Expanding the sample size and including diverse environmental conditions could provide a more comprehensive understanding of the variability in print outcomes. Additionally, a detailed cost analysis that includes operational expenses such as electricity, equipment maintenance, and labor is essential for a holistic evaluation of cost-effectiveness. Investigating the impact of different post-processing techniques on model quality and durability, as well as practical clinical trials to assess real-world applications, would further validate the study's conclusions. Lastly, continuous updates to research should be made to keep pace with technological advancements in 3D printing, ensuring that findings remain relevant and applicable to current practices.

#### Conclusion:

Overall, the study reveals the practical implications of resin selection and printing methodologies for enhancing the feasibility and economic viability of 3D-printed dental models. The strategic use of thicker models enables significant advancements in treatment planning precision and patient outcomes. This research advocates for a considered approach to model wall thickness, encouraging broader adoption of additive manufacturing

technologies in dental practices. By embracing these insights, dental professionals can achieve operational efficiencies and elevate the quality of care, advancing the integration of 3D printing in the field.

#### References

1. Narula R, Nair GK, Gaur A. 3 D PRINTING IN DENTISTRY. *Guident*. 2017 Dec 1;11(1).
2. Alharbi N, Wismeijer D, Osman RB. Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations. *J Prosthet Dent*. 2016;115(6):760-767.
3. Azari A, Nikzad S. The evolution of rapid prototyping in dentistry: a review. *Rapid Prototyp J*. 2009;15(3):216-225.
4. Bibb R, Winder J, Ali A. Rapid manufacture of removable partial denture frameworks. *Rapid Prototyp J*. 2007;13(2):95-99.
5. Dawood A, Marti Marti B, Sauret-Jackson V. 3D printing in dentistry. *Br Dent J*. 2015;219(11):521-529.
6. Jia C, Jiang Y, Chen W. 3D printing of transparent dental aligners. *J Healthc Eng*. 2019;2019:1-8.
7. Kessler R. Dental 3D printing for aligners: an overview of technology and market trends. *J Orthod Dentofacial Orthop*. 2019;156(3):378-387.
8. Schmidt A, Rechmann P. In-office fabrication of removable dental prostheses. *Int J Comput Dent*. 2018;21(1):29-39.
9. Vaid NR, Mendez C. 3D printing in orthodontics: a critical review. *Am J Orthod Dentofacial Orthop*. 2019;156(2):287-294.
10. Ghazal M, Albogha MH, Hajeer MY, Al-Samadani KH. Digital workflow of 3D-printed dental replicas, radiographic imaging, and intraoral scanning: a preliminary study. *Saudi Dent J*. 2019;31(3):351-357. doi:10.1016/j.sdentj.2019.04.005.