REVIEW ARTICLE

Effect of Build Orientation on Mechanical and Physical Properties of Additively Manufactured Resins Using Digital Light Processing Technology in Dentistry: A Systematic Review

Sujatha Paranna[1], Nilima Thosar[2], Aditi Kanitkar[3]

Received on: 02 October 2024; *Accepted on:* 19 November 2024; *Published on:* 20 December 2024

Abstract

Aim: The aim of this systematic review was to evaluate the effect of build orientation on the mechanical and physical properties of additively manufactured resin using digital light processing (DLP).

Background: The properties of 3D-printed materials are influenced by various factors, including the type of additive manufacturing (AM) system and build orientation. There is a scarcity of literature on the effect of build orientation on the mechanical and physical properties of additively manufactured resins using DLP technology in dentistry.

Methods: This study followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines and was registered in PROSPERO. The formulated population, intervention, comparison, outcome (PICO) question was "What is the effect of build orientation on the mechanical and physical properties of additively manufactured resins produced using DLP in dentistry." The search strategy used three main electronic databases and an additional manual search was done until February 2024. All the studies that evaluated the correlation of build orientation and the properties of printed resin using DLP were included. Two different analysis was used for *in vivo* and *in vitro* studies to assess the risk of bias.

Review results: On search 237 studies were yielded for systematic review, out of which 13 studies were included for the systematic review evaluation. On evaluation and reviewing the included studies, though the build orientation angle influenced the properties of printed resins the results obtained were varied as 90° angle had increased compressive strength, low surface roughness, and best accuracy. The 0° angle had better wear resistance, tensile strength, and high flexural strength. There was no influence of build orientation on microhardness, shear bond strength, gloss and color difference. The studies on denture base showed that 45° build angle showed the truest with best accuracy.

Conclusion: The build orientation angle effects on both the mechanical and physical properties of the additively manufactured resin but varies with each property. The build orientation can be chosen based on the type of properties to be achieved based on the treatment modality.

Clinical significance: Based on the systematic review results the specific build orientation angle should be used during fabrication of any denture designs, crowns, and bridges as it is correlated with the properties to be achieved by particular designs.

Keywords: 3D printing, Additive manufacturing, Crowns, Dental materials, Denture design, Orientation.

The Journal of Contemporary Dental Practice (2024): 10.5005/jp-journals-10024-3759

Introduction

In the current age of digital dentistry, computer-aided design and computer-aided manufacturing (CAD–CAM) plays a crucial role in the field of dentistry.[1,2] Due to the technological improvements, particularly in computer-aided manufacturing systems, additive manufacturing (AM) is becoming increasingly important. Additive manufacturing constructs 3D restorations by incrementally adding materials in a sequential and layered manner. This technology also aids in the production of simulated models, surgical prostheses, devices, and dentures.[3–7] The 3D printing has several advantages compared with the CAM system. These include reduced material consumption, cost effectiveness, lower hardware investment, the ability to create several complicated designs, and lower total manufacturing costs.[8]

Digital light processing (DLP) is an additive method that utilizes photopolymerization, where layers of photosensitive resin are cured using ultraviolet light. Additionally, there is progress in the advancement of elastomeric resins that can undergo polymerization by the implementation of the DLP system.[9–11]

[1]Department of Pediatric and Preventive Dentistry, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Sangli; Sharad Pawar Dental College, Datta Meghe Institute of Higher Education and Research (Deemed to be University), Sawangi, Wardha, Maharashtra, India

[2]Department of Pediatric and Preventive Dentistry, Sharad Pawar Dental College, Datta Meghe Institute of Higher Education and Research (Deemed to be University), Sawangi, Wardha, Maharashtra, India

[3]Department of Prosthodontics, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Sangli, Maharashtra, India

Corresponding Author: Sujatha Paranna, Department of Pediatric and Preventive Dentistry, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Sangli; Sharad Pawar Dental College, Datta Meghe Institute of Higher Education and Research (Deemed to be University), Sawangi, Wardha, Maharashtra, India, Phone: +91 7259215556, e-mail: drsuji912@gmail.com

How to cite this article: Paranna S, Thosar N, Kanitkar A. Effect of Build Orientation on Mechanical and Physical Properties of Additively Manufactured Resins Using Digital Light Processing Technology in Dentistry: A Systematic Review. J Contemp Dent Pract 2024;25(9):891–903.

The progress in 3D-printed photopolymerizable resins and the DLP system has had a significant impact on the field of dentistry. In order to achieve successful material properties, it is important to take into account the several aspects that influence the qualities of printed products.[12] The parameters that influence the printing process include the orientation of the print, the duration of post curing, and the specific printing technology employed.[13–17] Multiple investigations have shown that the mechanical qualities of 3D-printed objects are also affected by the printing orientation. The build angle has an impact on various properties of the printed material, including accuracy, flexural modulus and strength, compressive and shear bond strength and surface roughness.[7,18–25]

Although there have been research examining the accuracy and mechanical properties of 3D print resins and the build angle, these studies are restricted and further exploration is needed. Systematic studies have been conducted on the wear resistance, methods, nanoparticles and comparison of 3D-printed resins with conventional and milled techniques, including the mechanical properties of polymethylmethacrylate as a denture base material, 3D printing of restorative materials using stereolithography and 3D printing in cleft care.[26–28] However, there is a lack of reviews comparing the influence of build orientation on the properties of 3D-printed materials processed by DLP technique. Therefore, we aim to assess the effect of build orientation on the mechanical and physical properties of resins printed using DLP. However, there is currently no systematic research available on the link between the build angle and its correlation with the qualities of 3D-printed material. An analysis of the mechanical properties of 3D print resins in relation to the build orientation will yield additional insights into their correlation. Therefore, comprehensive systematic review was conducted to examine the mechanical and physical properties of 3D-printed resin utilizing DLP at various build orientations and to address the research question "What is the effect of build orientation on the mechanical and physical properties of additively manufactured resins produced using DLP in dentistry?"

Methods

Protocol and registration: This systematic review was carried out in accordance with the guidelines provided by the preferred reporting items for systematic reviews and meta-analysis (PRISMA) 2020. The protocol is registered under PROSPERO with registration ID – CRD42024537497.

Source of support: Nil
Conflict of interest: None

Research methodology – Experiments conducted both *in vitro* and *in vivo*.

The PICO framework consisted of the fundamental elements: Population, intervention, comparison, and outcome.

Population – 3D-printed resin specimens with any desired shape or form.

Intervention – Build orientation angle of 45 and 90 degrees.

Comparison – Build orientation angle of 0 degrees.

Result – Mechanical and physical characteristics.

The review included both *in vitro* and *in vivo* study designs, exclusively complete textual articles published within the mentioned year in English language and 3D printing exclusively utilizing DLP. Studies that evaluated the build orientation angles of 0, 45, and 90 degrees and its association with mechanical or physical characteristics of the resin produced through 3D printing.

Case reports, review articles, and conference papers, studies on the vertical or horizontal orientations not specific to build angle, studies which did not compare the build orientation parameter and its effect on the mechanical and physical properties were excluded.

Research Studies Information and Search Strategy

The process of searching for relevant papers was conducted in the databases PubMed, Scopus, and Web of Science until February 2024. We utilized the Mendeley reference manager program to handle our references.

The search approach utilized a combination of Medical Subject Headings (MeSH) and input phrases as keywords, including Boolean operators such as AND, OR, and NOT (Table 1). The results were validated for duplicate articles and then removed.

Two reviewers Sujatha Paranna and Aditi Kanitkar (SP and AK) did a manual search for papers to potentially include in the review, depending on the references of selected research.

Article selection was done by two reviewers Sujatha Paranna and Nilima Thosar (SP and NT) evaluated and selected the titles and abstracts to be included in the review. Subsequently, consensus was reached to address any disagreements and was reassessed by thoroughly reading the entire document. The papers included underwent a thorough evaluation by SP and NT. Any differences

Table 1: Search strategy based on the PICO focused research question

Research question	*What is the effect of build orientation on the mechanical and physical properties of additively manufactured resins produced using DLP in dentistry*
Population #1	Crowns OR Fixed dental prosthesis OR bridge OR FDP OR Fixed partial prosthesis OR resin-bonded bridge OR bar OR specimen OR implant crown AND dental materials AND Denture OR Partial AND Printing OR three dimensional OR 3D AND Printing OR additive manufacturing OR computer–aided design OR software OR DLP OR digital light processing OR composite resins OR acrylic resins
Intervention #2	Orientation OR anisotropy OR spatial OR Build orientation OR build angle OR print angle AND 90° angle OR 90 degree angle AND 45° angle OR 45 degree angle OR vertical build OR horizontal build OR oblique build OR algorithms
Comparison #3	Orientation OR build angle OR anisotropy OR print angle AND 0° angle OR 0 degree angle OR vertical orientation OR horizontal orientation OR oblique orientation OR algorithms
Outcome #4	Impression accuracy OR trueness OR precision OR *in vivo* study OR dimensional measurement accuracy OR elastic modulus OR flexural strength OR materials testing OR surface properties OR hardness OR pliability OR temperature OR wear OR mechanical properties OR fracture toughness OR shear strength OR wear resistance OR chipping OR surface roughness OR color OR color stability OR color alteration OR shade OR color change OR Bond OR adaptation OR gap OR marginal discrepancy OR internal discrepancy
Search	#1 AND 2# AND 3# AND 4#

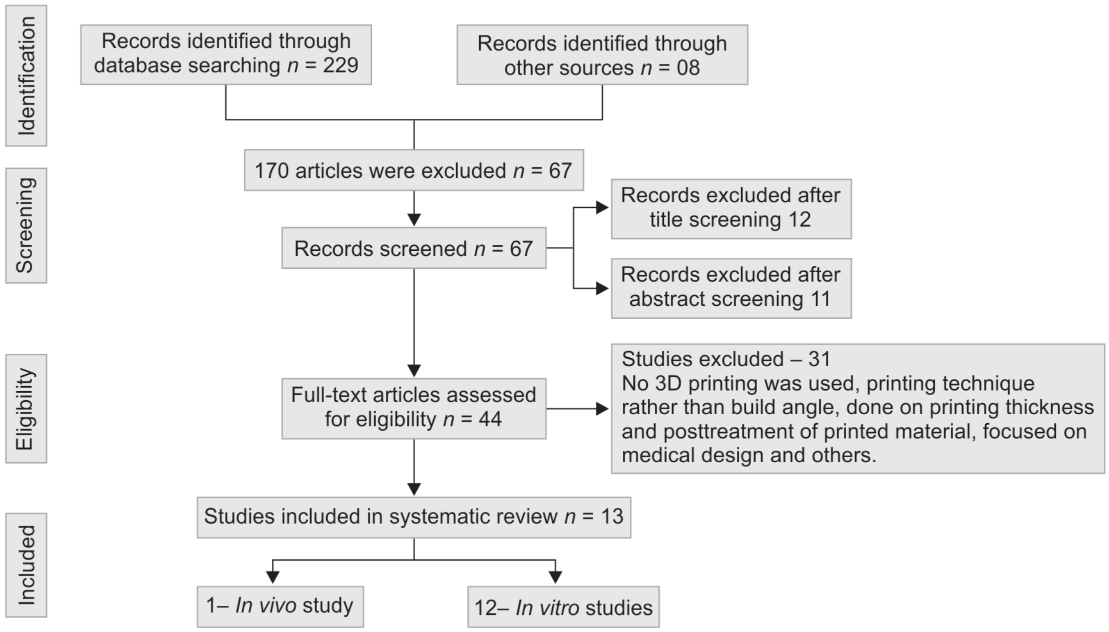

Fig. 1: Preferred reporting items for systematic reviews and meta-analysis flow diagram for the selection of studies

were handled, and consensus was reached by the third reviewer, AK. Finally, SP was responsible for formatting the data, evaluating the included publications, and summarizing the outcomes of this systematic review.

Risk of Bias (RoB)

Assessment of Potential bias of In Vivo Studies

Two reviewers SP and NT, utilized the Cochrane risk of bias (RoB) tool to evaluate the risk of bias of *in vivo* studies, as outlined in the handbook.cochrane.org. Any conflicts between these two reviewers were addressed by a third author AK. The areas of sequence generation, allocation concealment, blinding of outcome assessment, incomplete outcome data, and selective outcome reporting were evaluated and categorized as either low risk of bias, unclear or high risk of bias. The threshold for converting the Cochrane RoB tool to Agency for Healthcare Research and Quality standards: A study is considered good quality if all criteria are met; it is considered fair quality if one criterion is not met (indicating high risk of bias for one domain), two criteria are unclear and it is considered poor quality if one criterion is not met (indicating high risk of bias for one domain), two criteria are unclear. If two or more criteria were identified as having a high or unclear risk of bias, the paper was deemed to be of poor quality.[29] A RoB assessment figure was created using Review Manager (RevMan, version 5.3, Denmark).

Assessment of Potential Bias in In Vitro Studies

The Quality Assessment Tool for *In Vitro* investigations (QUIN) was employed to evaluate the potential for bias of *in vitro* investigations.[30] SP and NT thoroughly examined and compared the complete texts of the studies included to evaluate the potential for bias in the articles. Any discrepancies in their opinions were resolved through conversation until a consensus was reached. The QUIN comprises a set of 12 criteria. Each criterion was evaluated based on the following categories: Adequately specified, inadequately specified, not specified, or not applicable. These ratings were assigned points such as adequately specified as 2, inadequately specified as 1, not specified as 0 and not applicable will be excluded criteria from calculation. The scores were added to obtain a total score for a particular study.

The study's risk level was assessed as high, medium, or low, utilizing the following formula:

$$\text{Final score} = \frac{(\text{Total score} \times 100)}{(2 \times \text{number of criteria applicable})}$$

The scores thus obtained were used to grade the *in vitro* study as high, medium, or low risk. A considerable risk of bias is associated with a value below 50%. The bias between 50 and 70% indicates a medium level of risk and below 70% is considered low.

Study Quality Assessment

For *in vivo* study, Grading of recommendations assessment, development and evaluation (GRADE) tool was used to synthesis the quality of evidence and the levels of evidence were classified as very low, low, moderate, or high.[31] Authors (SP and AK) graded the study according to five criteria of study limitations, inconsistency, indirectness, imprecision, and publication bias as defined in the GRADE-tool adaptation.

Results

Selection of Studies

The search yielded a total of 237 items, obtained from both the specified database and manual searching. Out of these, 170 papers were eliminated after removing duplicate articles, publications published as reviews, and articles published in book chapters. This left us with 67 articles for review. We evaluated 67 publications based on their title and abstract to determine if they should be included in the review. After reviewing the title and abstract, 54 articles were excluded for the following reasons: They lacked a focus on 3D printing, concentrated on printing techniques rather than build angle and print orientation, examined printing thickness, post-treatment of printed material, emphasized on medical design and build angles other than to be included for review.[1,3,5,7,14,18–20,23] Ultimately, we incorporated a total of 13 articles into our review (Fig. 1).

Key Features of the Included Studies

The summary of the included research was classified according to the following criteria: Study design, sample size, materials, specimen geometry, physical and mechanical properties, and testing method. Only one study conducted *in vivo* investigated the wear resistance of the 3D-printed materials based on the angle of construction.[32] The sample size of the included studies varied from 5 to 20 participants per group. The geometry of the specimen exhibited numerous forms, including disc-shaped, cylindrical, dumbbell-shaped, and rectangular. One study created an interim crown, a three-unit bridge, and an implant-supported crown. Five research focused on the denture base resin, specifically investigations. The mechanical parameters of tensile strength, compressive strength, fracture load, flexural strength, and modulus, were evaluated using the universal testing method.[33,34] A single study assessed the gloss and color variation of the material by employing a glossmeter and spectrophotometer. The research included in the analysis utilized several ways to evaluate the surface roughness (Table 2).

Analysis of the Mechanical Properties

Wear Volume

In a single *in vivo* study conducted by Lee et al., the wear volume of the interim crown cemented on the mandibular molar was evaluated and compared.[32] The study included both a control group using conventional self-cure resin and experimental groups with crowns printed at 0, 45, and 90 degrees. The wear volume was analyzed using 3D inspection software, and the evaluations were conducted at 1-week intervals. The interim crown printed at 0 degrees exhibited the least amount of wear when compared with those printed at 45 and 90 degrees. Therefore, it is recommended to use a 0 degree angle for 3D-printing interim crowns.

Compressive and Tensile Strength

An *in vitro* study was conducted to assess the tensile and compressive strength. The results were contradictory, suggesting that a 0-degree angle should be used to enhance tensile strength, while a 90-degree angle should be used to enhance compression strength.[34]

Fracture Load

Alkhateeb et al. conducted a study to investigate the impact of the build angle on the fracture load of 3-unit interim fixed dental prostheses.[34] They compared two types of 3D print resin, Asiga and NextDent, and found that Asiga resin had a higher fracture load at 45 degrees, followed by 0 and 90 degrees. On the other hand, NextDent resin showed a higher fracture load at 0 degrees, followed by 45 and 90 degrees.[34]

Surface roughness of 3D-printed provisional indirect restorations and implant supported interim crown:

de Castro et al. conducted a study to assess the surface roughness and maximum profile valley depth of 3D-printed provisional indirect restorations following tooth brushing. Regardless of the print angle, it was noted that there was no variation in the surface roughness and maximum profile valley depth. A separate study examined the surface roughness of interim crowns supported by implants. The results showed that the group with a build angle of 90 degrees had the least surface roughness.[35] Khanlar et al. conducted an assessment of the surface roughness of 3D-printed resin.[25] The findings indicated that the printing group with a 45-degree angulation reported the greatest surface roughness. In a separate investigation, a profilometer was employed to assess the surface hardness. The results indicated that there was no discernible relationship between the print angle and the surface roughness.[36,37]

Flexural Modulus and Flexural Strength

A study conducted by de Castro found that the flexural modulus and strength of the tested material were lower than those of the control material [Polymethylmetacrylate (PMMA) CAD/CAM provisional material], regardless of the angle.[22] A separate study examined the rectangular 3D-printed samples to assess their flexural strength. The findings indicated that the specimens with a 0 degree orientation had the highest flexural strength, surpassing the 45 and 90 degree groups.[38]

Shear Bond Strength

Disc-shaped specimens were manufactured and assessed for their shear bond strength. It was noted that there was no variation in the shear bond strength across the groups at 0, 45, and 90-degree angles.[25]

Surface Roughness and Hardness of Denture Base Resins

The Vickers hardness test was used to assess the hardness. The print angle did not impact the surface hardness of the 3D-printed resin.[37] Another investigation demonstrated that the microhardness was not affected by the build angle.[22]

Analysis of the Physical Properties

Gloss and Color Difference

A single study examined the levels of glossiness and color variation in 3D-printed resin.[35] The gloss surface values and color difference was evaluated using glossmeter and spectrophotometer, respectively, observed no difference.[39]

Accuracy and Trueness Assessment

The 3D metrology software was used to analyze the trueness and precision of denture base resins in all the experiments included. Three investigations were conducted on the fabrication of denture bases using 3D-printing technology. These studies shown that the highest levels of accuracy and trueness were achieved when the printing process was carried out at a 45-degree angle.[40–42] The specimens printed with a 0-degree orientation exhibited the maximum flexural strength in comparison to the groups produced at 45 and 90 degrees.[36] The surface roughness was unaffected by the printing orientation.[37]

Evaluation of the Risk of Bias

This systematic review includes a total of 13 studies, which were evaluated to determine their risk of bias. The one *in vivo* study's RoB summary showed low risk of bias (Figs 2 and 3). Twelve *in vitro* studies were evaluated for RoB among them four research omitted the specifics of sample size computation. None of the studies provided information regarding the details of the outcome assessors and the process of blinding. One study accurately documented operator details.[42] All studies included information on their aims, objectives, comparison group data, methodology, result measurement, and statistical analysis details. The individual studies had a total score that varied between 12 and 16. The ultimate score, as determined by the methodology, fell within the range of 46.15–61.5%. Eight of the studies included in the analysis were found

Table 2: Characteristics of 13 studies included for systematic review

Author and year	*Title of the article*	*Study design*	*Sample size (n)/ Materials*	*Geometry of specimen*	*Physical properties/ method of testing*	*Mechanical properties/ method of testing*	*Results*
Lee et al.[32] 2022	Comparison of wear of interim crowns in accordance with the build angle of digital light processing 3D printing: A preliminary *in vivo* study	Preliminary *in vivo* study	$N = 05$ conventional $n = 01$– UNIFAST III self-cured 3D-printing group $n = 03$ – RAYDENT C&B	Interim crown – Mandibular molar teeth	–	Wear volume/3D inspection software	Wear resistance of conventional interim crown was similar to 0 degree angle. Recommended printing angle is 0 degrees
Farkas et al.[33] 2023	The influence of printing layer thickness and orientation on the mechanical properties of DLP 3D-printed dental resin. polymers	*In vitro* study	$N = 24$. Tensile strength $n = 12$ Compressive strength $n = 12$/NextDent C&B MFH	D638-14 test method (Dumbbell shape) D695-02a test method (cylinder shape)	–	Tensile strength/UTM Compressive strength/ UTM	To increase the tensile strength of this resin after printing, an angle of 0 is recommended. To increase the compression strength of dental crowns, bridges, or other dental products printing layer direction of 90 is recommended
Alkhateeb et al.[34] 2023	Fracture load of 3D-printed interim three-unit fixed dental Prostheses: Impact of printing orientation and post-curing time. polymers	*In vitro* study	150/resin $n = 10$/group NextDent and ASIGA	3-unit interim fixed dental prostheses	–	Fracture load/UTM	ASIGA resin – Higher fracture load with 45 followed by 0 and 90 degrees. NextDent – Higher fracture load with 0 followed by 45 and 90 degrees. The fracture resistance of 3D-printed 3-unit interim fixed dental prostheses increased with 0 and 45 printing orientations
de Castro et al.[35] 2023	Effect of build orientation in gloss, roughness and color of 3D-printed resins for provisional indirect restorations	*In vitro* study	Toothbrushing wear – $n = 10$/group Color difference – $n = 5$/group Control – PMMA CAD-CAM block Vita CAD-Temp. Cosmos-Temp SLA Cosmos-Temp DLP PriZma-Bioprov DLP Nanolab/Wilcos – LCD	Control– rectangular shape. 3D-printed resin – disc shape	Gloss – glossmeter Surface roughness – Laser confocal microscope Maximum profile valley depth – Laser confocal microscope. Color difference – Spectrophotometer	–	Build orientation had no influence in the Gs values, regardless of the 3DRs and TB cycles. Build orientation had no influence in the Sa regardless of the resin and TB cycles. No differences in Rv were observed among 3DRs, irrespective of the orientation. Regardless of the resin and aging period, there was no difference in the ΔE00 among different build orientations

(Contd...)

Table 2: *(Contd...)*

Author and year	*Title of the article*	*Study design*	*Sample size (n)/ Materials*	*Geometry of specimen*	*Physical properties/ method of testing*	*Mechanical properties/ method of testing*	*Results*
Ortega et al.[37] 2023	Comparison of surface roughness of additively manufactured implant-supported interim crowns fabricated with different print orientations	*In vitro* study	*n* = 10/group GC Temp PRINT	Implant-supported maxillary right premolar full-contour crown	–	Surface roughness – Optical 3D measurement system at × 50 magnification with 3D measurement software program	The 90-degree group obtained the lowest surface roughness mean values, whereas the 45-degree group demonstrated the highest surface roughness mean values
de Castro et al.[35] 2022	Effect of build orientation in accuracy, flexural modulus, flexural strength, and microhardness of 3D-printed resins for provisional restorations	*In vitro* study	*N* = 20/ group *n* = 10 after 24 h *n* = 10 after 1 year *n* = 10/group for microhardness evaluation. Control – PMMA CAD/CAM provisional material (Vita Temp/Vita). Cosmos-Temp SLA Cosmos- Temp DLP PriZma-Bioprov DLP Nanolab/Wilcos – LCD	Bar-shaped – accuracy Disc-shaped – microhardness	–	Accuracy – The reference (digital) values. Flexural modulus and flexural strength – UTM. Microhardness – SEM and Energy dispersive X-ray spectroscopy	Except for Cosmos-DLP, the 90° orientation demonstrated the best overall accuracy in all dimensions evaluated. Regardless of orientation flexural modulus was lower than the control. 90°-Cosmos-SLA had higher flexural strength after 1 year of aging. Build orientation had no influence on microhardness of the 3DRs
Al-Dulaijan et al.[38] 2023	Effect of printing orientation and postcuring time on the flexural strength of 3D-printed resins	*In vitro* study	*n* = 10/group. Control – Heat-polymerized (HP) acrylic resin. ASIGA DentaBASE Next Dent Base	Rectangular specimens	–	Flexural strength – UTM	The results showed that specimens printed at 0-degree orientation for both materials (ASIGA and NextDent) had the highest flexural strength when compared to 45- and 90-degree groups
Khanlar et al.[25] 2023	Surface roughness and shear bond strength to composite resin of additively manufactured interim restorative material with different printing orientations	*In vitro* study	*n* = 20/group Control group – Conventional bis-acrylic composite resin (Protemp 4; 3M ESPE) – Injection mold technique Experimental groups – Clearfil SE Bond 2 – DLP Clearfil Majesty ES Flow (Low) – DLP	Disk-shaped specimen	–	Surface roughness – SEM Shear bond strength -UTM	The 45-degree angulation printing group reported the highest surface roughness. The CNT showed the highest surface roughness parameter. No statistically significant difference was found in the shear bond strength among the groups

(Contd...)

Table 2: *(Contd...)*

Author and year	*Title of the article*	*Study design*	*Sample size (n)/ Materials*	*Geometry of specimen*	*Physical properties/ method of testing*	*Mechanical properties/ method of testing*	*Results*
Cameron et al.[40] 2022	Trueness assessment of additively manufactured maxillary complete denture bases produced at different orientations	*In vitro* study	*n* = 10/ group Next Dent Denture 3D+ Build orientations of 0, 15, 45, 60, and 90 degrees	Maxillary complete denture	Trueness – 3D inspection and metrology software program	–	The color deviation maps showed that a 45- to 90-degree print orientation was truest overall and that the addition of support struts to the cameo and intaglio surfaces improved the trueness of the maxillary denture bases
Song et al.[41] 2023	Effect of build orientation and layer thickness on manufacturing accuracy, printing time, and material consumption of 3D printed complete denture bases	*In vitro* study	*n* = 10/group DENTCA Denture Base II	An edentulous maxillary model	Accuracy – 3D metrology software	–	The L45° group showed the best accuracy over the entire intaglio surface. The worst manufacturing accuracy was observed in the B90° group. The resin consumption in the 90° build orientation groups (L90°, P90°, and B90°) was the lowest. The 0° group required the shortest printing time
Chaiamornsup et al.[42] 2023	Effects of build orientation and bar addition on accuracy of complete denture base fabricated with digital light projection: An *in vitro* study	*In vitro* study	*n* = 6/group Dima Print Denture Base	Mandibular and maxillary CD bases and normal-shaped tooth sockets	Accuracy – 3D CAD software	–	The trueness without a bar was the highest at 45° and with bars was the highest at 0° for denture base and intaglio surfaces
Al-Dulaijan et al.[36] 2022	Comparative evaluation of surface roughness and hardness of 3D-printed resins materials	*In vitro* study	*n* = 10/group Heat-polymerized (HP) – Major Base.20. ASIGA (AS) – ASIGA DentaBASE (DLP). Next Dent Base – Next Dent (SLA)	Disc-shaped specimen	–	Surface roughness – Profilometer. Hardness – Vickers tester	Printing orientation did not affect the surface roughness. AS, 90-degree orientation showed a significant decrease in VH. ND showed no significant difference in VH with different printing orientations
Lee et al.[32] 2022	Effect of layer thickness and printing orientation on the color stability and stainability of a 3D-printed resin material	*In vitro* study	*n* = 10 C&B 5.0 Hybrid; ARUM	Disc-shaped specimen	Color stability and stainability – Spectrophotometer	–	The printing orientation of 0 degrees may decrease the discoloration of 3D-printed resins

PMMA, polymethylmetacrylate; SEM, scanning electron microscope to have a moderate risk of bias [25,34,35,37–40,42] while four studies were determined to have a high risk of bias (Table 3).[25,33–35,37–42]

In Vivo Study Quality Assessment

An *in vivo* study included for the GRADE assessment showed low quality of evidence (Table 4). This could be because of inconsistencies in the blinding of the participants and allocation concealment but the positive aspect was more than 80% was the participants were analyzed with only one drop out participant. The participants included in the study could help in decision making with effective final outcome.

Discussion

The 3D printing is a technology that allows for the creation of intricate structures with less time and materials compared with traditional manufacturing methods.[43–45]

ISO/ASTM 52900: 2015 defines AM as the technique of combining materials to create items layer by layer using 3D model data, as opposed to subtractive manufacturing methods.[2] 3D printing enables the creation of intricate structures without material wastage, making it a more cost-effective option compared with subtractive manufacturing methods in terms of both hardware investment and overall production costs.[46–48] 3D printing has been utilized in dentistry to fabricate micro-prostheses, specifically on lays and crowns. The manufacture of complete removable dentures requires less time and money, as well as fewer materials, compared with CAD/CAM technology.[49]

In recent years, DLP has emerged as a cost-effective method within the AM group of vat photopolymerization. Digital light processing is well-suited for the production of small, precise parts that are used in various industries. It is particularly attractive to dentistry researchers due to its potential in digital applications. This method can be utilized to make dental crowns, bridges, and other dental devices. The development of this technology may be traced back to 1987 when Dr Larry Hornbeck, an individual affiliated with Texas Instruments, first created it.[49]

The characteristics of components produced using 3D printing technology are affected by the material used and the specific production process employed.[49] The properties of printed material are influenced by the interlayer bond and changes in the local polymerization process, which are the causes for this.[50–52] Therefore, it is crucial to have a comprehensive grasp of the mechanical characteristics of materials used in dental applications. The features of vat photopolymerized products are influenced by several factors, including build orientation, angle acuteness viscosity, color, and transparency of the photopolymerized monomer.[53–57]

With the DLP, the mechanical properties of materials are affected by the build angle.[58] Anisotropy refers to the variation in physical qualities based on the angle.[32] There is a scarcity of literature on anisotropy in DLP parts, likely due to the fact that this technique is more recent compared with stereolithography or Polyjet. Given that DLP technology generates pixelated layers, enhancing the resolution becomes a crucial concern. The primary reason for the difference in quality between vertical and horizontal construction orientations in DLP portions is pixilation, as determined through experimental testing.[51]

This is the first systematic review conducted to document and analyze the available studies that compare the build angle of 0, 45, and 90 degrees, as well as the mechanical and physical properties of 3D-printed resins using DLP technique. The present systematic review assessed the studies conducted on the impact of build angle on the mechanical and physical characteristics of 3D-printed resin. There are a total of 13 studies covered. Among the 13 investigations, one is a preliminary *in vivo* study, while the remaining 12 are *in vitro* studies. The assessment of the studies

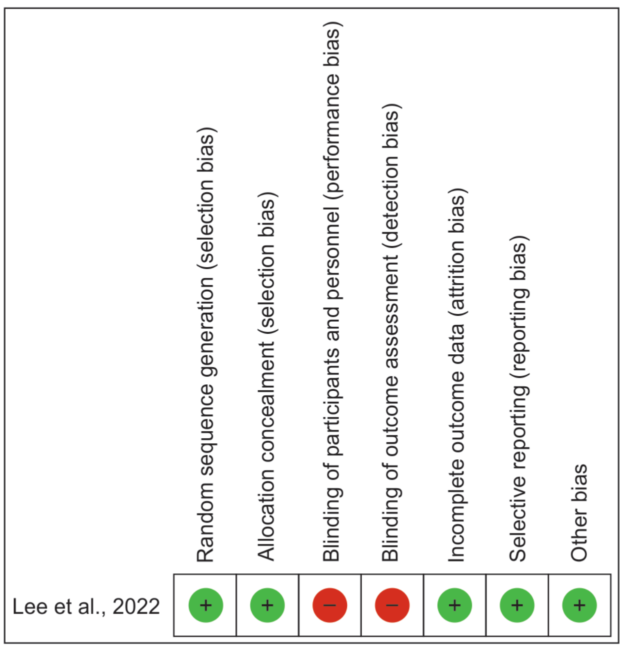

Fig. 2: Risk of bias of *in vivo* study

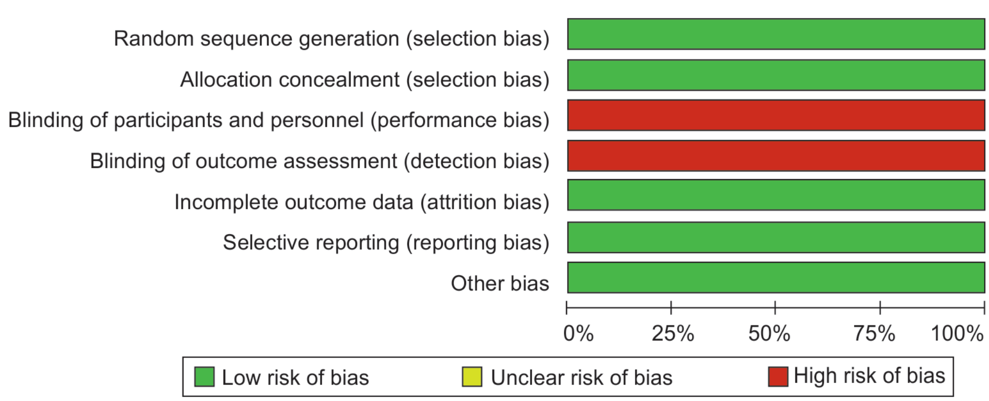

Fig. 3: Risk of bias summary of *in vivo* study

Table 3: Risk of bias of *in vitro* studies

Risk of bias	*Farkas et al.*[33] *2023*	*Alkhateeb et al.*[34] *2023*	*de Castro et al.*[35] *2023*	*Ortega et al.*[37] *2023*	*de Castro et al.*[35] *2022*	*Al-Dulaijan et al.*[38] *2023*	*Khanlar et al.*[25] *2023*	*Cameron et al.*[40] *2022*	*Song et al.*[41] *2023*	*Chaiamornsup et al.*[42] *2023*	*Al-Dulaijan et al.*[36] *2022*	*Lee et al.*[32] *2022*
Clearly stated aims/objectives	2	2	2	2	2	2	2	2	2	2	1	2
Detailed explanation of sample size calculation	0	2	0	1	1	2	1	2	0	0	1	2
Detailed explanation of sampling technique	0	0	0	0	0	0	0	0	0	0	0	0
Details of comparison group	2	2	2	2	2	2	2	2	2	2	2	2
Detailed explanation of methodology	2	2	2	2	2	2	2	2	2	2	2	2
Operator details	0	0	0	0	0	0	0	0	0	1	0	0
Randomization	0	0	0	0	0	0	0	0	0	0	0	0
Method of measurement of outcome	2	2	2	2	2	2	2	2	2	2	2	2
Outcome assessor details	0	0	0	0	0	0	0	0	0	0	0	0
Blinding	0	0	0	0	0	0	0	0	0	0	0	0
Statistical analysis	2	2	2	2	2	2	2	2	2	2	2	2
Presentation of results	2	2	2	2	2	2	2	2	2	2	2	2
Total	12	14	12	13	13	14	13	14	12	13	12	14
GRADE (%)	46.15 High risk	53.84 Medium risk	46.15 High risk	50 Medium risk	53.84 Medium risk	53.84 Medium risk	50 Medium risk	53.84 Medium risk	46.15 High risk	50 Medium risk	46.15 High risk	53.84 Medium risk

indicated that the build angle had an impact on the mechanical and physical properties. A single study assessed the physical characteristics of resin, including its glossiness and color difference, and found that these attributes remained unaffected by the construction angle. The mechanical and physical properties of the 3D-printed resin will be further examined in relation to the build angles of 0, 45, and 90 degrees.

Anisotropy refers to the variation in material qualities based on direction, as mentioned above. Dizon et al. conducted a study that found anisotropy in the restorations produced utilizing a DLP technique.[58] 3D printing materials are manufactured using a technology that involves stacking, which directly impacts the chemical bonding between each layer. This could be one of the factors contributing to anisotropy. The fabrication technique of three-dimensionally printed materials has an impact on the mechanical properties of 3D-printed resins. The authors have stated that the mechanical properties are influenced by the orientation during printing.[59]

The analysis of the trials included in this research indicates that the build orientation angle has a significant impact on the mechanical properties of 3D-printed resins. The mechanical qualities assessed in this systematic review include wear volume, compressive and tensile strength, fracture load, flexural strength, hardness and microhardness, surface roughness, trueness, and correctness of the printed resin.

The volume loss value can be used to measure the absolute wear volume. If there is a significant change in volume owing to wear, it can lead to a decrease in vertical dimension and movement of the opposing teeth in the case of anterior restorations. This can result in alterations to the way the teeth occlude, including changes in the way the frontal and lateral guidance the jaw movements. Hence, the temporary crown must possess sufficient wear resistance.[32] The sole *in vivo* study described in the systematic review found that the interim crowns printed at 0 degrees had the shortest height and wear volume, whereas the interim crowns printed at 90 degrees had the maximum height and wear volume. Therefore, our current investigation was constrained by the characteristics of the products and the size of the sample.

The maximum yield point is a crucial feature to consider during the design of any product.[33] The compressive strength was enhanced when the resin was printed perpendicular to the printer's tray at a 90° angle. This phenomenon may be attributed to the augmented dimensions of the printed layer's cross section and the surplus material, resulting in an expanded plastic zone prior to the occurrence of necking and eventual fracture.[60,61] Furthermore, arranging the layers in a pancake-like fashion enhances the compressive ability.[62]

The compressive strength of a structure with a 0° build angle is the lowest due to the compressing forces being aligned with the length of the printed layers. This alignment causes a buckling effect, which greatly diminishes the structural capacity of the specimen.[33]

The tensile strength was enhanced when the resin was printed at a 0° angle. The objects printed at 0° and 45° angles experience gravitational bending, resulting in an uneven tensile load. On the other hand, objects produced at a 90° angle have flanks that remain almost parallel to each other.[33] Despite variations in the construction angle, resulting in different values for compressive strength and tensile strength, the obtained values were in close proximity to the Young's modulus.[33]

Both the 0° and 45° angles exhibited a high fracture load, whereas the 90° angle had the lowest values; however, the

Table 4: Grading of recommendations assessment, development and evaluation assessment for reported *in vivo* study

Author and year	*Study limitations*	*Inconsistency*	*Indirectness*	*Imprecision*	*Publication bias*	*Overall quality*
Lee et al.[32] 2022	X	V	V	X	V	++

Overall quality: ++++ high, +++ moderate, ++ low, + very low. V, no downgrading; X, one-point downgrading; XX, two-point downgrading

difference was not statistically significant. This is due to the orientation of the printing layer. When the object is oriented at a 45° angle, the printing layers are not parallel but instead follow an oblique trajectory.[34]

Upon the application of load, the specimens exhibited splitting, which can be attributed to the inadequate interlayer bonding. It was noted that the strength of connection between layers was lower compared with the bonding inside each individual layer. Kebler et al. also reported the same findings about the vertical orientation of the load, which is parallel to the direction of the printed layer.[23] Controversial results arose when the structural failure of 3D-printed resins were reported. The discrepancy in the outcomes may be attributed to the arrangement of the examined specimens, such as the shape of the bars and the presence of a three-unit bridge. The authors hypothesized that there would be a correlation between the formation of layering fractures and the orientations of the printing process. The variation was associated with the orientation of failure (either horizontal or vertical/splitting along the length of the specimen), which could be linked to the printing direction. The vertical breaking occurred predominantly at a 90° angle, providing evidence of inadequate interlayer bonding.[34] In terms of support position and removal, as well as fracture resistance, the clinical application of the 0° and 45° support positions is higher compared with the 90° angle.[34]

The glossiness and surface roughness were unaffected by the build orientation at 0°, 45°, and 90° angles, even after subjecting the material to 10,000 tooth brushing cycles and 200 hours of UVB aging.[35] In this investigation conducted by de Castro et al, pixels were detected at a 0° orientation, whereas layers with stacked orientations of 45° and 90° were discovered. The layers were connected in a stepwise manner at a 45° orientation, resulting in an increase in surface roughness due to the presence of step edges, commonly referred to as the staircase effect. Polishing the outside surface is advised as it will eliminate minor imperfections created by the staircase effect in inclined orientations. Changes in build orientation will not impact the surface roughness of the polished 3D-printed specimen.[63,64] The properties of the filler particles, including their form, size, and type, have an impact on the surface roughness and gloss of the printed resin. The surface roughness can also be influenced by the type and concentration of fillers.[35]

The complete specimen examined by Ortega et al. exhibited a superficial typography that is characteristic of AM.[37] The method utilizes a sequential layering procedure that results in a surface texture characterized by horizontal grooves and superficial roughness. The printed resin at 0° exhibited the presence of craters and wide parallel ridges. The resin printed at a 45° angle exhibited distinct slanted ridges, while the resin produced at a 90° angle displayed perpendicular ridges on its surface. Therefore, while taking into account the roughness of the surface, it is advisable to use a 90° print orientation in order to optimize the results of AM for interim restorations.[39]

A further investigation yielded contentious findings, indicating that the resin printed at a 0° angle had the maximum level of surface roughness, while the group printed at a 45° angle had the lowest roughness.[25] This study also examined shear bond strength, and the results showed that the 45° angle had the highest value compared with the 0° and 90° angles. Therefore, there was a discrepancy in the shear bond strength and surface roughness based on the build orientation. This may be attributed to the presence of elevated peaks and deep valleys on the surface of the printed specimens.[25] The specimen with a 45° angle displayed distinct stepwise and step borders between its layers. The surface topography was assessed using scanning electron microscope (SEM) examination, revealing that the resin printed at a 0° angle displayed craters of varying sizes, while the 45° group revealed oblique ridges on the surface. The group with a 90° angle had surfaces that were characterized by a mixture of round and amorphous features.[25]

Hence, if we solely focus on surface roughness, it is advisable to use a 90-degree print orientation to enhance the quality of AM interim restorations. This recommendation applies to the specific combination of manufacturing trinomial (technology, printer, and material) and selected protocol.[39]

The study conducted by Al-Dulaijan et al. found that the 0-degree (horizontal) orientation groups exhibited the highest flexural strength values in both 3D-printed resins, when compared with the 45-degree and 90-degree orientations.[36] This phenomenon may be attributed to a change in the arrangement of the printing layers, shifting from a parallel orientation to a perpendicular orientation with respect to the load direction. This alteration can lead to enhanced adhesion within the layers themselves, as compared with orientations at 45 degrees and 90 degrees.[65,66] The SEM data reflect this observation, as they reveal more uniform strata in the 0-degree groups.[37] This finding is consistent with a prior study conducted by Kebler et al., which suggested that aligning the printed layers perpendicular to the load direction leads to greater strength compared with when the layers are parallel to the load direction.[23]

Here is a summary of the mechanical properties of 3D-printed resin and the build angle, based on the articles included for systematic review and its discussion. The mechanical parameters of wear volume, fracture load, flexural strength, and tensile strength were found to be superior for resin printed at a 0-degree angle. In one study, the adoption of a 0 degree build angle resulted in a decrease in surface roughness. However, another study produced conflicting results, suggesting that the build angle had no impact on surface roughness. Out of the research included, only one examined the shear bond strength and found no variation among the three construction angles. Nevertheless, the compressive strength exhibited superior performance when the material was printed at a 90-degree angle.

The number of layers and exposure morphologies of the denture fluctuate depending on the specific print orientations. Specifically, we identified negative deviations in the labial area of the denture border at angles of 0° and 45°. This problem arises due to the inadequate replication of the precise boundary at the denture border, resulting from the resolution limitations of the DLP device.[67] Furthermore, the denture base undergoes alterations in its intaglio and cameo surfaces, specifically in the concave and convex regions, depending on the build orientation. The unreacted monomer likely remained in the concave region, leading to excessive polymerization as a positive deviation.[68] Sagging of the denture flange was observed, most likely due to its weight and the positioning of the supporting structures during the AM output process.[69]

A study was conducted to examine the accuracy and precision of the 3D-printed denture base resin materials. According to all the experiments, the 45° angle demonstrated the highest level of precision that was deemed acceptable. A study conducted by Song et al. in 2023 examined the angles associated with labial, buccal, and posterior orientation. The findings revealed that a labial orientation with a 45-degree angle demonstrated the highest accuracy.[41] The color deviation maps of the 0-degree group reveal the accuracy of the palate and flanges of the denture base. However, significant deviations are observed in vast areas, as evidenced by the presence of yellow areas of deviation.[40] The occurrence of this phenomenon can be attributed to the staircase effect that occurs during the deposition of photopolymer layers.[70]

In a study conducted by Cameron et al. in 2022, the accuracy of the denture base was examined on maxillary edentulous models positioned at angles ranging from 45 to 90 degrees and found that the overall assessment demonstrated the highest level of accuracy. The inclusion of support struts contributes to enhancing the accuracy of the denture base.[40]

Two studies assessed the precision of denture bases created using various construction angles. The maximum level of accuracy was observed with a build angle of 45 degrees.[40,42] Chaiamornsup et al. conducted a study to compare the accuracy of measurements with and without the addition of bars. The results showed a significant difference, indicating that measurements without a bar had the most accuracy at a 45° angle, while measurements with a bar had the highest accuracy at a 0° angle for denture base and intaglio surfaces. The use of bars decreased the lateral deformation of the denture base by preventing the denture model from tipping over, while also providing support for the floating components and overhanging materials.[42] Although there was no substantial change, there were variances in data indicating an increase in surface values at angles of 45° and 90° compared with 0° angle.[37] The changes seen can be ascribed to the presence of printing layers with distinct steps between them, where a 0° angle corresponds to a single layer in the horizontal plane.[71–73] If the hardness is poor, it is more likely to result in scratches, damage to the resin surface, and potential changes in dimensions due to mechanical denture brushing or chewing hard food substances.[64,72]

de Castro et al. determined that the build orientation of the 3D-printed resin had no impact on its glossiness. The gloss diminished after undergoing 10,000 cycles of toothbrushing, necessitating periodic polishing of the material. The surface gloss of the material was not affected by the build orientation, even after UV ageing. This is because the oxidation of unreacted monomers and amines, which are related to the material's composition, rather than the build angle, does not impact the optical properties of the material. The color stability of the material was determined by the type and concentration of photoinitiators, rather than the orientation. As a result, no discernible difference was found.[35]

In a study conducted by Lee et al.[32] in 2022, the researchers examined the color change of 3D-printed resin using three different aging mediums. They discovered that the resin printed at a 0° angle had a lower color change value compared with those printed at 45° and 90° angles.[38] Based on their findings, they suggested utilizing a 0° build angle. This study contradicts the findings of de Castro et al., who found that the build angle had no impact on color change. Both studies agree that the main factors responsible for color change are the surface roughness of the material and the pH of the aging medium, which causes erosion of the printed surface.[34] Colorants are easily adsorbed by resins that have rough surfaces. The acidity of drinks can cause erosion on resin restorations, which can affect their appearance. The contact angle of a liquid on the resin surface serves as a measure of the overall surface energy and wettability. This, in turn, impacts the color stability and susceptibility to staining of the 3D-printed resin when it is submerged in a staining solution. A low contact angle suggests high wettability, suggesting that discoloration by the staining solution is more probable. The study found that the mean contact angle was not significantly affected by the layer thickness or printing orientation. This suggests that the contact angle may not be correlated with color stability or stainability.[73,74]

Limitations

- The *in vitro* studies included in the review had moderate to high risk of bias.
- There were variations in the design of the specimens.
- The type of resin materials used could have had a confounding effect on the outcomes.
- Though the review included both *in vitro* and *in vivo* studies, only one *in vivo* study was retrieved.

Future Directions

The future of DLP technology in dentistry, particularly regarding the impact of build orientation on additively manufactured resins, is promising. Digital light processing technology future in dentistry promises improved patient care, advancement in dental manufacturing and customized patient care based on the needs of patient.

In addition, the *in vitro* studies included had a moderate to high risk of bias, and only one *in vivo* study was evaluated. The *in vitro* studies exhibited variability in the results due to differences in design and testing methods. As a result, these inconsistencies prevented us from conducting a meta-analysis.

Conclusion

The subsequent conclusions can be derived from this comprehensive systematic review.

- The build angle at which the resin is printed significantly impacts its mechanical and physical properties.
- When evaluating interim crowns produced using 3D printing technology, a 90-degree orientation angle results in higher compressive strength, lower surface roughness, and improved precision.
- A 0-degree orientation angle exhibits superior wear resistance, tensile strength, and high flexural strength; however, the build angle does not impact microhardness, shear bond strength, gloss, or color difference.
- For denture bases, a 45-degree orientation angle is the most accurate and true.

Clinical Significance

The build orientation angle should be considered when desirable properties of the prosthetic designs are to be fabricated. In crown and bridge fabrication, the compression strength to be considered and based on that the particular build orientation angle has to be applied for additively manufactured resins and in contrast when the denture to be fabrication the trueness and the tensile strength are important hence the build orientation for particular design should be applied.

Orcid

Sujatha Paranna https://orcid.org/0000-0003-4959-4498
Nilima Thosar https://orcid.org/0000-0003-3339-781X
Aditi Kanitkar https://orcid.org/0000-0002-6661-0931

References

1. Mayer J, Stawarczyk B, Vogt K, et al. Influence of cleaning methods after 3D printing on two-body wear and fracture load of resin-based temporary crown and bridge material. Clin Oral Investig 2021;25(10):5987–5996. DOI: 10.1007/s00784-021-03905-9.
2. van Noort R. The future of dental devices is digital. Dent Mater 2012;28(1):3–12. DOI: 10.1016/j.dental.2011.10.014.
3. Kessler A, Reymus M, Hickel R, et al. Three-body wear of 3D printed temporary materials. Dent Mater 2019;35(12):1805–1812. DOI: 10.1016/j.dental.2019.10.005.
4. Sarment DP, Sukovic P, Clinthorne N. Accuracy of implant placement with a stereolithographic surgical guide. Int J Oral Maxillofac Implants 2003;18(4):571–577. PMID: 12939011.
5. Hazeveld A, Huddleston SJ, Ren Y. Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. Am J Orthod Dentofacial Orthop 2014;145(1):108–115. DOI: 10.1016/j.ajodo.2013.05.011.
6. Reyes-Sevilla M, Kuijs RH, Werner A, et al. Comparison of wear between occlusal splint materials and resin composite materials. J Oral Rehabil 2018;45(7):539–544. DOI: 10.1111/joor.12636.
7. Tahayeri A, Morgan M, Fugolin AP, et al. 3D printed versus conventionally cured provisional crown and bridge dental materials. Dent Mater 2018;34(2):192–200. DOI: 10.1016/j.dental.2017.10.003.
8. Ligon SC, Liska R, Stampfl J, et al. Polymers for 3D printing and customized additive manufacturing. Chem Rev 2017;117(15):10212–10290. DOI: 10.1021/acs.chemrev.7b00074.
9. Xiang H, Wang X, Ou Z, et al. UV-curable, 3D printable and biocompatible silicone elastomers. Prog Org Coat 2019;137(1):105372. DOI: 10.1016/j.porgcoat.2019.105372.
10. Chen F, Li R, Sun J, et al. Photo-curing 3D printing robust elastomers with ultralow viscosity resin. J Appl Polym Sci 2021;138(10):49965. DOI: 10.1002/app.49965.
11. Patel DK, Sakhaei AH, Layani M, et al. Highly stretchable and UV curable elastomers for digital light processing based 3D printing. Adv Mater 2017;29(15). DOI: 10.1002/adma.201606000.
12. Gad MM, Fouda SM. Factors affecting flexural strength of 3D-printed resins: A systematic review. J Prosthodont. 2023;32(S1):96–110. DOI: 10.1111/jopr.13640.
13. Choi Y, Yoon J, Kim J, et al. Development of bisphenol A glycidylmethacrylate and trimethylolpropane triacrylate based stereolithography 3D printing materials. Polymers (Basel). 2022;14(23):5198. DOI:10.3390/polym14235198.
14. Derban P, Negrea R, Rominu M, et al. Influence of the printing angle and load direction on flexure strength in 3D printed materials for provisional dental restorations. Materials (Basel). 2021;14(12):3376. DOI: 10.3390/ma14123376.
15. Tian Y, Chen C, Xu X, et al. A review of 3D printing in dentistry: Technologies, affecting factors, and applications. Scanning 2021. DOI: 10.1155/2021/9950131.
16. Moradi M, Aminzadeh A, Rahmatabadi D, et al. Experimental investigation on mechanical characterization of 3D printed PLA produced by fused deposition modeling (FDM). Mater Res Express 2021;8(3):035304. DOI: 10.1088/2053-1591/abe8f3.
17. Moradi M, Aminzadeh A, Rahmatabadi D, et al. Statistical and experimental analysis of process parameters of 3D nylon printed parts by fused deposition modeling: Response surface modeling and optimization. J Mater Eng Perform 2021;30(7):5441–5454. DOI: 10.1007/s11665-021-05848-4.
18. Osman RB, Alharbi N, Wismeijer D. Build angle: Does it influence the accuracy of 3D-printed dental restorations using digital light-processing technology? Int J Prosthodont 2017;30(2):182–188. DOI: 10.11607/ijp.5117.
19. Park GS, Kim SK, Heo SJ, et al. Effects of printing parameters on the fit of implant-supported 3D printing resin prosthetics. Materials (Basel) 2019;12(16):2533. DOI: 10.3390/ma12162533.
20. Ryu JE, Kim YL, Kong HJ, et al. Marginal and internal fit of 3D printed provisional crowns according to build directions. J Adv Prosthodont 2020;12(4):225–232. DOI: 10.4047/jap.2020.12.4.225.
21. Yu BY, Son K, Lee KB. Evaluation of intaglio surface trueness and margin quality of interim crowns in accordance with the build angle of stereolithography apparatus 3-dimensional printing. J Prosthet Dent 2021;126(2):231–237. DOI: 10.1016/j.prosdent.2020.04.028.
22. de Castro EF, Nima G, Rueggeberg FA, et al. Effect of build orientation in accuracy, flexural modulus, flexural strength, and microhardness of 3D-Printed resins for provisional restorations. J Mech Behav Biomed Mater 2022;136(1):105479. DOI: 10.1016/j.jmbbm.2022.105479.
23. Kebler A, Hickel R, Ilie N. In vitro investigation of the influence of printing direction on the flexural strength, flexural modulus and fractographic analysis of 3D-printed temporary materials. Dent Mater J 2021;40(3):641–649. DOI: 10.4012/dmj.2020-147.
24. Alharbi N, Osman R, Wismeijer D. Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations. J Prosthet Dent 2016;115(6):760–767. DOI: 10.1016/j.prosdent.2015.12.002.
25. Khanlar NL, Revilla-León M, Barmak AB, et al. Surface roughness and shear bond strength to composite resin of additively manufactured interim restorative material with different printing orientations. J Prosthet Dent 2023;129(5):788–795. DOI: 10.1016/j.prosdent.2021.08.010.
26. Prause E, Hey J, Beuer F, et al. Wear resistance of 3D-printed materials: A systematic review. Dent Rev 2022;2(2):100051. DOI: 10.1016/j.dentre.2022.100051.
27. Della Bona A, Cantelli V, Britto VT, et al. 3D printing restorative materials using a stereolithographic technique: A systematic review. Dent Mater 2021;37(2):336–350. DOI: 10.1016/j.dental.2020.11.030.
28. Al-Thobity AM, Gad MM. Effect of silicon dioxide nanoparticles on the flexural strength of heat-polymerized acrylic denture base material: A systematic review and meta-analysis. Saudi Dent J 2021;33(8):775–783. DOI: 10.1016/j.sdentj.2021.08.008.
29. Viswanathan M, Patnode CD, Berkman ND, et al. Recommendations for assessing the risk of bias in systematic reviews of health-care interventions. J Clin Epidemiol 2018;97(1):26–34. DOI: 10.1016/j.jclinepi.2017.12.004.
30. Sheth VH, Shah NP, Jain R, et al. Development and validation of a risk-of-bias tool for assessing in vitro studies conducted in dentistry: The QUIN. J Prosthet Dent 2022:S0022–3913(22)00345-6. DOI: 10.1016/j.prosdent.2022.05.019.
31. Ryan R, Hill S. How to GRADE the quality of the evidence. Cochrane Consumers and Communication Group. Version 3.0. 2016.
32. Lee H, Son K, Lee DH, et al. Comparison of wear of interim crowns in accordance with the build angle of digital light processing 3D printing: A preliminary in vivo study. Bioengineering (Basel) 2022;9(9):417. DOI: 10.3390/bioengineering9090417.
33. Farkas AZ, Galatanu SV, Nagib R. The influence of printing layer thickness and orientation on the mechanical properties of DLP 3D-printed dental resin. Polymers (Basel) 2023;15(5):1113. DOI: 10.3390/polym15051113.
34. Alkhateeb RI, Algaoud HS, Aldamanhori RB, et al. Fracture load of 3D-printed interim three-unit fixed dental prostheses: Impact of printing orientation and post-curing time. Polymers (Basel). 2023;15(7):1737. DOI: 10.3390/polym15071737.
35. de Castro EF, Nima G, Rueggeberg FA, et al. Effect of build orientation in gloss, roughness and color of 3D-printed resins for provisional

indirect restorations. Dent Mater 2023;39(7):e1–e11. DOI: 10.1016/j.dental.2023.05.002.
36. Al-Dulaijan YA, Alsulaimi L, Alotaibi R, et al. Comparative evaluation of surface roughness and hardness of 3D printed resins. Materials (Basel). 2022;15(19):6822. DOI: 10.3390/ma15196822.
37. Ortega NM, Revilla-León M, Ortega R, et al. Comparison of surface roughness of additively manufactured implant-supported interim crowns fabricated with different print orientations. J Prosthodont 2024;33(2):141–148. DOI: 10.1111/jopr.13645.
38. Al-Dulaijan YA, Alsulaimi L, Alotaibi R, et al. Effect of printing orientation and postcuring time on the flexural strength of 3D-printed resins. J Prosthodont 2023;32(S1):45–52. DOI: 10.1111/jopr.13572.
39. Lee EH, Ahn JS, Lim YJ, et al. Effect of layer thickness and printing orientation on the color stability and stainability of a 3D-printed resin material. J Prosthet Dent 2022;127(5):784.e1–784.e7. DOI: 10.1016/j.prosdent.2022.01.024.
40. Cameron AB, Evans JL, Abuzar MA, et al. Trueness assessment of additively manufactured maxillary complete denture bases produced at different orientations. J Prosthet Dent 2024;131(1):129–135. DOI: 10.1016/j.prosdent.2021.12.025.
41. Song S, Zhang J, Liu M, et al. Effect of build orientation and layer thickness on manufacturing accuracy, printing time, and material consumption of 3D printed complete denture bases. J Dent 2023;130(1):104435. DOI: 10.1016/j.jdent.2023.104435.
42. Chaiamornsup P, Katheng A, Ha R, et al. Effects of build orientation and bar addition on accuracy of complete denture base fabricated with digital light projection: An in vitro study. J Prosthodont Res 2023;67(4):641–646. DOI: 10.2186/jpr.JPR_D_22_00245.
43. Tiwari A, Murugan NA, Ahuja R. Advanced Engineering Materials and Modeling. Advanced Material Series. Hoboken, NJ, USA:Wiley. 2016; p. 528.
44. Hanon MM, Ghaly A, Zsidai L, et al. Investigations of the mechanical properties of DLP 3D printed graphene/resin composites. Acta Polytech Hung 2021;18(8):143–161. DOI: 10.12700/APH.18.8.2021.8.8.
45. Gibson I. Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing. 2nd edition Berlin/Heidelberg, Germany:Springer. 2015; p. 498.
46. Stansbury JW, Idacavage MJ. 3D printing with polymers: Challenges among expanding options and opportunities. Dent Mater 2016;32(1):54–64. DOI: 10.1016/j.dental.2015.09.018.
47. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: A review of the available streams. Int J Dent 2014;2014:783948. DOI: 10.1155/2014/783948.
48. Kanazawa M, Inokoshi M, Minakuchi S, et al. Trial of a CAD/CAM system for fabricating complete dentures. Dent Mater J 2011;30(1):93–96. DOI: 10.4012/dmj.2010-112.
49. Digital Micromirror Device. Available online: http://research.omicsgroup.org/index.php/Digital_ micromirror_device.
50. Nold J, Wesemann C, Rieg L, et al. Does printing orientation matter? In-vitro fracture strength of temporary fixed dental prostheses after a 1-year simulation in the artificial mouth. Materials (Basel) 2021;14(2):259. DOI: 10.3390/ma14020259.
51. Monzón M, Ortega Z, Hernández A, et al. Anisotropy of photopolymer parts made by digital light processing. Materials (Basel) 2017;10(1):64. DOI: 10.3390/ma10010064.
52. International Organization for Standardization. ISO 4049:2019—Dentistry—Polymer-based restorative materials. 5th edition. Geneva, Switzerland:ISO. 2019. Available from: https://www.iso.org/standard/67596.html.
53. Alharbi N, Osman RB, Wismeijer D. Factors influencing the dimensional accuracy of 3D-printed full-coverage dental restorations using stereolithography technology. Int J Prosthodont 2016;29(5):503–510. DOI: 10.11607/ijp.4835.
54. Unkovskiy A, Bui PH, Schille C, et al. Objects build orientation, positioning, and curing influence dimensional accuracy and flexural properties of stereolithographically printed resin. Dent Mater 2018;34(12):e324–e333. DOI: 10.1016/j.dental.2018.09.011.
55. Chaiamornsup P, Iwasaki N, Yasue T, et al. Effects of build conditions and angle acuteness on edge reproducibility of casting patterns fabricated using digital light projection. Dent Mater J 2020;39(1):135–140. DOI: 10.4012/dmj.2018-401.
56. Vitale A, Cabral JT. Frontal conversion and uniformity in 3D printing by photopolymerisation. Materials (Basel) 2016;9(9):760. DOI: 10.3390/ma9090760.
57. Revilla-León M, Meyers MJ, Zandinejad A, et al. A review on chemical composition, mechanical properties, and manufacturing work flow of additively manufactured current polymers for interim dental restorations. J Esthet Restor Dent 2019;31(1):51–57. DOI: 10.1111/jerd.12438.
58. Dizon JRC, Espera AH, Chen Q, et al. Mechanical characterization of 3D-printed polymers. Addit Manuf 2018;20(1):44–67. DOI: 10.1016/j.addma.2017.12.002.
59. Ibrahim A, Shehawy DE, El-Naggar G. Fracture resistance of interim restoration constructed by 3D printing versus CAD/CAM technique (in vitro study). Ain Shams Dent J 2020;23(1):13–20. DOI: 10.21608/ASDJ.2020.140010.
60. Zhou W, Chen D, Shulkin Y, et al. Ductile failure and delayed necking in polyethylene. Plast Fail Anal Prev 2001;2001(1):25–30. DOI: 10.1016/B978-188420792-1.50005-6.
61. Ye J, André S, Farge L. Kinematic study of necking in a semi-crystalline polymer through 3D Digital Image Correlation. Int J Solids Struct 2015;59(1):58–72. DOI: 10.1016/j.ijsolstr.2015.01.009.
62. Urechescu H, Pricop M, Pricop C, et al. Thermoplastic materials used for fabrication of maxillary obturator prostheses experimental compression and traction tests. Mater Plast 2017;54(3):477–480. DOI: 10.3390/polym15051113.
63. Oropallo W, Piegl LA. Ten challenges in 3D printing. Eng Comput 2015;32(1):135–148. DOI: 10.1007/s00366-015-0407-0.
64. Pandey PM, Reddy NV, Dhande SG. Part deposition orientation studies in layered manufacturing. J Mater Process Technol 2007;185(1–3):125–31. DOI: 10.1016/j.jmatprotec.2006.03.120.
65. Gad MM, Fouda SM, Abualsaud R, et al. Strength and surface properties of a 3D-printed denture base polymer. J Prosthodont 2022;31(5):412–418. DOI: 10.1111/jopr.13413.
66. Srinivasan M, Kalberer N, Kamnoedboon P, et al. CAD-CAM complete denture resins: An evaluation of biocompatibility, mechanical properties, and surface characteristics. J Dent 2021;114(1):103785. DOI: 10.1016/j.jdent.2021.103785.
67. Gao H, Yang Z, Lin WS, et al. The effect of build orientation on the dimensional accuracy of 3D-printed mandibular complete dentures manufactured with a multijet 3D printer. J Prosthodont 2021;30(8):684–689. DOI: 10.1111/jopr.13330.
68. Jin MC, Yoon HI, Yeo IS, et al. The effect of build angle on the tissue surface adaptation of maxillary and mandibular complete denture bases manufactured by digital light processing. J Prosthet Dent 2020;123(3):473–482. DOI: 10.1016/j.prosdent.2018.12.014.
69. Tsai FC, Yang TC, Wang TM, et al. Dimensional changes of complete dentures fabricated by milled and printed techniques: An in vitro study. J Prosthet Dent 2023;129(4):608–615. DOI: 10.1016/j.prosdent.2021.06.042.
70. You SG, You SM, Kang SY, et al. Evaluation of the adaptation of complete denture metal bases fabricated with dental CAD-CAM systems: An in vitro study. J Prosthet Dent 2020;125(3):479–485. DOI: 10.1016/j.prosdent.2020.01.039.
71. Shim JS, Kim JE, Jeong SH, et al. Printing accuracy, mechanical properties, surface characteristics, and microbial adhesion of 3D-printed resins with various printing orientations. J Prosthet Dent. 2020;124(4):468–475. DOI: 10.1016/j.prosdent.2019.05.034.
72. Aati S, Akram Z, Shrestha B, et al. Effect of post-curing light exposure time on the physico-mechanical properties and cytotoxicity of 3D-printed denture base material. Dent Mater 2022;38(1):57–67. DOI: 10.1016/j.dental.2021.10.011.
73. Soares IA, Leite PKBDS, Farias OR, et al. Polishing methods' influence on color stability and roughness of 2 provisional prosthodontic materials. J Prosthodont 2019;28(5):564–571. DOI: 10.1111/jopr.13062.
74. Hamouda IM. Effects of various beverages on hardness, roughness, and solubility of esthetic restorative materials. J Esthet Restor Dent 2011;23(5):315–322. DOI: 10.1111/j.1708-8240.2011.00453.