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Clinical Assessment of 3D-Printed Versus Conventional Occlusal Devices: Best-Fit, Roughness, Wear, and Treatment Capability

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Abstract: *This study investigates the accuracy of stereolithography (SLA)-printed occlusal devices fabricated at orientations of 0° and 45°, addressing a gap in the literature regarding printing orientation, technology and clinical performance. Despite their nascent application, the clinical performance of these materials remains largely unexplored. The primary objective was to evaluate the clinical efficacy of 3D-printed occlusal devices (OC) in a prospective, double-blind study involving 40 participants divided into four groups: conventionally fabricated polymethyl methacrylate (PMMA) occlusal devices (CPMMA), CAD/CAM milled PMMA (MPMMA), and 3D-printed OCs at 0 degrees (3D 0°) and 45 degrees (3D 45°). Conventional impressions and gypsum casts were digitized and designed for milling from PMMA blocks, while the 3D-printed groups used Dental LT resin (Formlabs, Sommerville, MA, USA) in a Form 2 printer (Formlabs, MA, USA). Clinical assessments were conducted at baseline and six months post-treatment, focusing on OC surface roughness, OC surface wear, antagonist tooth wear, occlusal device fit, and therapeutic efficacy. One-way ANOVA and post hoc tests were applied for statistical analysis. Results showed no significant therapeutic differences among groups, although all participants exhibited improvements in palpation and mandibular movement scores ($p > 0.001$). No significant difference was observed in surface wear between the MPMMA and 3D 0° groups, while the difference between the other groups was significant ($p < 0.001$). Significant antagonist tooth wear variations ($p < 0.001$) were noted, with the MPMMA and 3D 0° groups showing less wear compared to the control group. The findings indicate that 3D-printed occlusal devices yield clinically acceptable outcomes, demonstrating performance comparable to traditional materials, with printing orientation potentially influencing antagonist tooth wear. The 3D-printed OC demonstrates adequate surface roughness, wear resistance, device fit, and therapeutic efficacy.*

Keywords: *Additive manufacturing, occlusal device, 3D printed resin, print orientation, digital dentistry*

1. Introduction

Dentistry is undergoing a pronounced digital transformation, with traditional workflows progressively supplanted by advanced three-dimensional technologies, notably additive manufacturing (AM; commonly referred to as 3D printing). AM employs computer-aided design (CAD) data, along with a range of material systems, to fabricate patient-specific devices by successive layer-wise deposition, in contrast to subtractive techniques that produce objects by removing material from prefabricated blocks [1]. Both additive and subtractive manufacturing processes are governed by international standards (ISO), which prescribe criteria for reproducibility, safety, dimensional accuracy and overall quality assurance in dental production [2]. The adoption of 3D printing has expanded markedly across oral and maxillofacial surgery, prosthodontics, and orthodontics, where its capacity for precise, customized fabrication offers clinical and workflow advantages [1,2].

Among orthodontic and restorative adjuncts, occlusal devices (OC) are widely used and have broad interdisciplinary applications, including the treatment of temporomandibular disorders (TMD), support during orthodontic therapy, and prevention of parafunctional damage. Their therapeutic efficacy

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derives from the redistribution of occlusal forces, the reduction of masticatory muscle hyperactivity and the mitigation of the deleterious sequelae of bruxism and TMD [3]. Conventional subtractive manufacturing (SM), principally milling, requires the fabrication of each device individually, a process that is comparatively time-consuming and generates substantial material waste [3]. By contrast, AM permits the concurrent production of multiple devices in a single build volume, necessitating the post-processing removal of support structures; the principle is used to develop various methods, especially the stereolithography (SLA) is one of the predominant AM modalities employed for device fabrication due to its resolution and material properties [4,5]. The SLA technology uses a laser beam to activate photo-initiators sequentially, resulting in local polymerisation of the directly exposed area. Since the object is manufactured layer by layer, it is anisotropic, meaning that its orientation relative to the printer's platform during fabrication affects its properties [6]. Research indicates that the orientation of 3D-printed OCs relative to the printer's build plate can significantly affect various factors. These include printing time, the need for support structures, the volume of material used, and the final product attributes, such as OC fit, surface roughness, wear, and mechanical properties [3,7–9]. Additionally, previous studies reported clinical observations that printing orientation is a determinant of the internal fit of 3D-printed occlusal devices by SLA [8,10,11].

This *in vivo* study investigates the accuracy of SLA-printed occlusal devices fabricated at 0° and 45° orientations, addressing a gap in research despite known effects of printing orientation, technology, and printer on device accuracy. The primary null hypothesis is that printing orientation does not affect the accuracy of SLA-printed occlusal devices in patients with TMD. The study also compares surface roughness, fit accuracy, wear, and therapeutic effects of 3D-printed vs. traditionally manufactured occlusal devices. The secondary null hypothesis is that 3D-printed occlusal devices are not inferior to traditional devices in therapeutic effects, clinical performance (surface roughness, wear, antagonist tooth abrasion, device fit).

2. Materials and methods

Conducted at the Department of Prosthodontics, Istanbul University, from January to June 2024 (ethical batch number TDK 2024/35910; ClinicalTrials.gov identifier: NCT05955222), this study involved 40 participants who met the following criteria: presence of maxillofacial pain, limited functional movements, a diagnosis of DC/TMD, absence of missing teeth or prostheses, and an age range of 18 to 60 years. A sample size calculation, employing an alpha of 0.05 and a power of 0.95, determined that 10 participants per group were necessary to detect a one-standard-deviation difference in the primary endpoint. Functional assessment involved the clinical examination component of the Turkish DC/TMD form, a validated diagnostic tool (International DC/TMD-Based Research Consortium) [12]. Subjective pain was assessed using a visual analog scale (VAS).

Type IV die-stone gypsum casts (Kulzer GmbH) were created from condensation silicone impressions (Speedex Putty and Light Body; Coltène). Participants were randomly assigned to four groups: conventionally fabricated PMMA occlusal devices (CPMMA), CAD/CAM milled PMMA (MPMMA), 3D-printed at 0 degrees (3D 0°), and 3D-printed at 45 degrees (3D 45°). Group randomization was conducted based on the days of the week. Patients who were examined on Monday were assigned to the PMMA group, those examined on Tuesday were assigned to the MPMMA group, patients examined on Wednesday were assigned to the 3D 0° group, and those examined on Thursday were assigned to the 3D 45° group (workflow detailed in Figure 1). Gypsum casts were digitally scanned (Dental Wings; Dental Wings Inc.) and saved as STL files. Exocad's Bite Occlusal Module was used to virtually design flat occlusal surface OCs, which then underwent dynamic occlusion adjustment in a virtual articulator. Roland DWX-52D machine was used for the milling group (Roland DGA Corp). Occlusal devices for the conventional group were produced from PMMA-based thermoformable disks [13]. Chairside occlusal adjustments were made with autopolymerizing acrylic resin (Integra acrylic; United Group Dental).

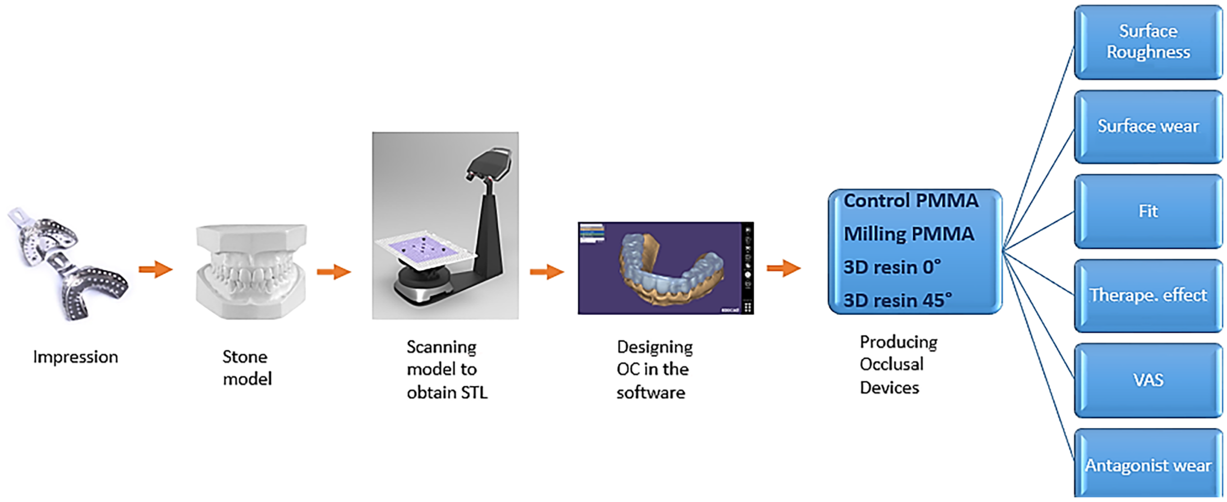

Figure 1. Workflow of the study groups

3D-printed OCs were additively manufactured with components oriented at 0° or 45° (Figure 2), using a 100 μm layer thickness as per manufacturer's recommendations. Ten OCs per group were printed using Dental LT resin (Formlabs, Sommerville, MA, USA) in a Form 2 printer (Formlabs, MA, USA). Following printing and illumination, OCs were carefully removed and cleaned ultrasonically in 96% ethanol (Otto Fischar GmbH) for 5 min (Sonorex Super RK1022, Bandelin). Specimens were then post-cured for 10 min in the LC-3DPrint Box (NextDent, Soesterberg, The Netherlands) according to the manufacturer's specifications. The Dental LT Clear V2 resin met the ISO 7405:2018 biocompatibility requirements and the ISO 10993-1:2018 biological assessment standards for medical devices, making it suitable for clinical light-curing 3D printing.

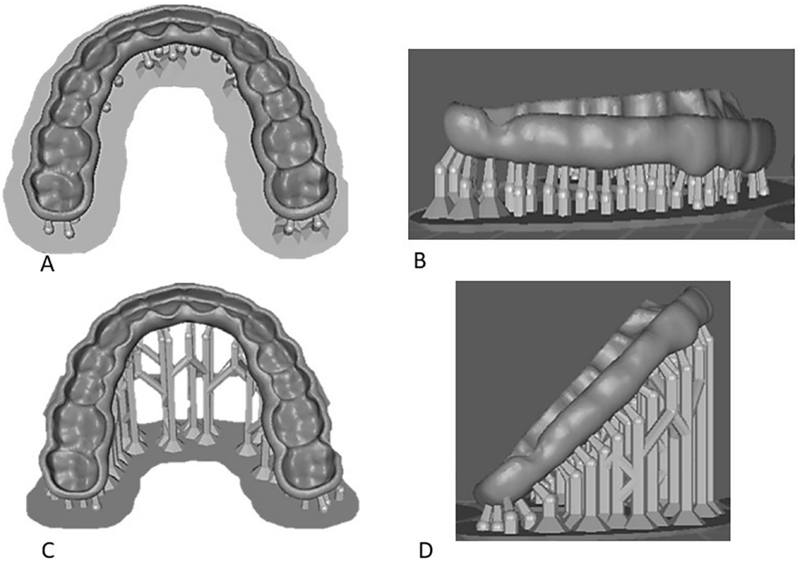

Figure 2. Images of designed occlusal devices. (A) Top view of 0° orientation; (B) Lateral view of 0° orientation; (C) Top view of 45° orientation; (D) Lateral view of 45° orientation

The OC's surface roughness was measured using a Surtronic profilometer (Taylor Hobson) prior to delivery. To assess occlusal wear and obtain an STL file, OCs were digitized at baseline and after six months of use with a high-resolution scanner with 0.03 mm sensitivity (Solutionix, Solutionix Inc.) An experienced CAD investigator performed superimpositions at 24 predefined points to evaluate occlusal wear: 16 posterior (buccal/palatal cusps of maxillary molars/premolars) and 8 anterior (incisal edges of canines/lateral incisors, plus 2 palatal points at the maxillary canines). Geomagic Control X (3D Software System) was used to analyse all STL files. Following initial alignment, models were best-fit aligned in the buccal area (100% sampling, 500 iterations). A 3D analysis was conducted, generating a color map showing deviations within a 1.0 mm range between the test and reference models. Occlusal wear was then quantified by analyzing depth and volume loss at the points mentioned before and wear loss recorded in μm.

Clinical efficacy was evaluated through the administration of the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) Axis I form at baseline and after six months of treatment. The evaluation included assessments of pain during mandibular movements, muscle tenderness, joint sounds, and the location and duration of facial and cranial pain. Pain levels were recorded by a Visual Analog Scale (VAS), ranging from 0 (no pain) to 100 (maximum pain), at both time points.

IBM SPSS Statistics version 26.0 (IBM Corp) was used, and a one-way ANOVA was conducted to compare the primary groups. The Kruskal-Wallis H test and post hoc analyses were utilised for non-parametric data. Qualitative data were analysed using the chi-squared test ($\alpha = 0.05$).

3. Results and discussions

Forty participants (average age 42 ± 2 years; 30% male, 70% female) were monitored over a period of 6 months. No adverse effects were noted. Adherence to the intervention protocol was documented. Statistical analyses were conducted using SPSS version 26, employing paired t-tests for continuous variables and chi-squared tests for categorical variables ($p < 0.05$). The principal outcome was the alteration in well-being score from baseline to 6 months. Secondary outcomes encompassed changes in satisfaction scores and adherence rates.

3.1. Surface roughness results between the groups

Table 1 and Figure 3 present the mean ± standard deviation values of surface roughness (Ra) for the groups. OC printing orientations were selected based on prior literature and clinical goals [9]. The 0-degree orientation, chosen for its shorter print time (due to fewer layers) and improved accuracy and surface properties, has been previously established [14,15]. The CPMMA group exhibited the highest surface roughness, at 0.070 ± 0.006 mm. However, MPMMA, 3D 0°, and 3D 45° groups demonstrated the following results, respectively: 0.048 ± 0.005, 0.063 ± 0.003, and 0.067 ± 0.004. No significant difference in surface roughness was observed between the CPMMA and 3D 45° groups. The difference in surface roughness was significant across all other study groups, except between these two. ($p < 0.001$) (Table 1). Both null hypotheses were partially accepted, showing that printing orientation does not affect the accuracy of SLA-printed occlusal devices, and that 3D-printed occlusal devices are not inferior to traditional devices in therapeutic effects, clinical performance (surface roughness, wear, antagonist tooth abrasion, device fit), or patient satisfaction. Surface roughness of interim restorations is critical for periodontal health. Roughness exceeding 0.2 μm promotes bacterial colonization, with 10 μm being the clinically acceptable limit [16,17]. In this study, coated materials exhibited Ra values between 0.038 μm and 0.087 μm, all of which were below this threshold. Conventional PMMA showed greater surface roughness than 3D-printed resins, likely due to compositional differences, a finding supported by previous research [18] and the work of Rizzante et al. [19]. This reinforces that material composition influences surface roughness.

Table 1. ANOVA 1-way and post hoc tests for surface roughness analysis

Anova 1-way	Sum of square	df	Mean square	F	Sig.
Between Groups	0.022	3	0.007	264.11	<0.001*
Within Groups	0.008	304	0.000		
Total	0.031	307			

Post hoc tests	Mean Difference	Std. Error	Sig.
CPMMA-MPMMA	0.0220	0.0008	<0.001*
CPMMA-3D 0°	0.0066	0.0008	<0.001*
CPMMA-3D 45°	0.0031	0.0008	0.002
MPMMA-3D 0°	0.0153	0.0008	<0.001*
MPMMA-3D 45°	0.0189	0.0008	<0.001*
3D 0°–3D 45°	0.0035	0.0008	<0.001*

Note: *$p < 0.001$.

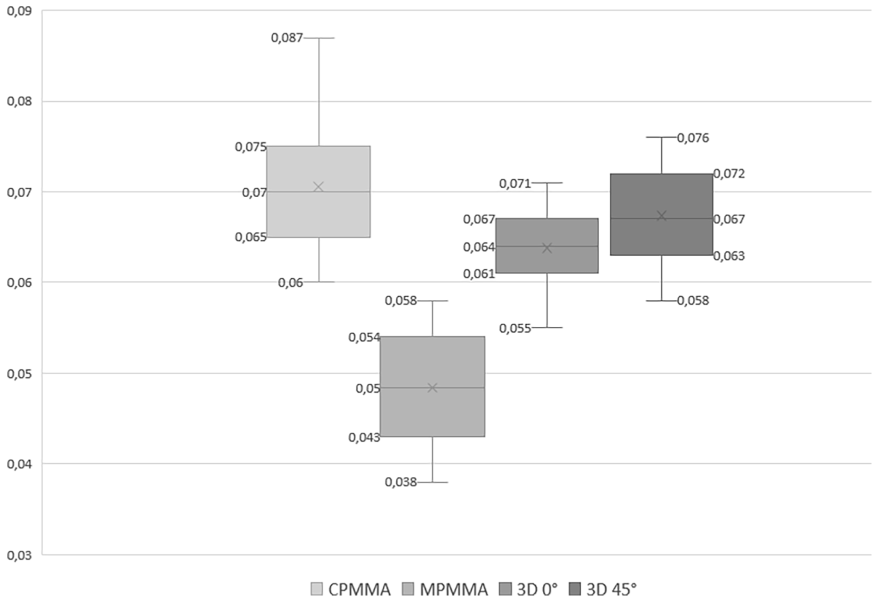

Figure 3. Surface roughness (Ra) values among tested subgroups

3.2. Surface wear results between the groups

The mean ± standard deviation values of surface wear for the study groups were detailed in Table 2. The CPMMA group demonstrated the highest surface wear value of 0.078 ± 0.64 mm. No significant difference in surface wear was observed between the MPMMA and 3D 0° groups. The difference in surface wear was found to be significant among all other study groups except these two groups. ($p < 0.001$) (Table 2). Anisotropy, a directional dependence of material properties inherent in additive manufacturing due to its layer-by-layer process, significantly affects the mechanical behavior of 3D-printed polymers [20]. Studies investigating occlusal devices reveal variations in wear resistance, accuracy, and fit related to build orientation and layer thickness [21,22]. While some researchers have confirmed anisotropic behavior in 3D-printed OC [21], others found no significant differences across orientations [1]. The interlayer adhesion is a crucial factor influencing anisotropy, potentially explaining observed variations in mechanical performance across different build orientations. Studies indicate that the mechanical properties of 3D-printed resins are anisotropic [9,14]. For example, more vertically printed restorations show higher compressive strength and occlusal devices exhibit greater fracture resistance when printed vertically [14]. Consequently, the build direction should be chosen based on the desired mechanical property and manufacturer guidelines. The analysis of surface wear revealed a significant difference between the 3D printed groups and the control group, with the former showing a statistically significant reduction in wear. This finding is noteworthy, particularly because the participants had temporomandibular joint disorder (TMD), known for exerting substantial bite forces. Despite these elevated forces, the 3D printed materials exhibited superior wear resistance compared to the control group. Thus, the data strongly supports the enhanced performance of 3D printed materials regarding wear resistance under the challenging conditions associated with TMD.

Table 2. Surface wear analysis using ANOVA 1-way and post hoc tests

Descriptive	**Mean ± SD (mm)**	**Minimum**	**Maximum**
CPMMA	0.078 ± 0.064	0.638	0.974
MPMMA	0.054 ± 0.046	0.413	0.647
3D 0°	0.055 ± 0.034	0.486	0.643
3D 45°	0.063 ± 0.055	0.544	0.775

Anova 1-way	**Sum of square**	**df**	**Mean square**	**F**	**Sig.**
Between groups	0.675	3	0.675	45.534	<0.001*
Within groups	1.167	236	1.167		
Total	1.842	239			

Post hoc tests	**Mean difference**	**Std. error**	**Sig.**
CPMMA-MPMMA	0.1304	0.0128	<0.001*
CPMMA-3D 0°	0.1254	0.0128	<0.001*
CPMMA-3D 45°	0.0642	0.0128	<0.001*
MPMMA-3D 0°	0.0050	0.0128	0.980
MPMMA-3D 45°	0.0661	0.0128	<0.001*
3D 0°-3D 45°	0.0611	0.0128	<0.001*

Note: $*p < 0.001$.

3.3. Surface wear results in antagonist natural teeth

Table 3 presents the mean ± standard deviation values of surface wear results in antagonist natural teeth after 6 months of treatment. Significant differences in antagonist tooth wear ($p < 0.001$) were observed between the control group and the study groups (Table 3). The degree of surface wear observed on natural antagonist teeth was statistically similar between the MPMMA and 3D 0° groups. Printing orientation significantly affected the amount of antagonist tooth wear. The 3D 0° group exhibited statistically significantly less wear on opposing teeth than the 3D 45° group, indicating that printing orientation influences abrasive wear. Notably, the 3D 0° group consistently exhibited the lowest wear levels throughout the study.

Table 3. Analysis of the wear points (in mm) of antagonist natural teeth

Descriptive	Mean ± SD (mm)	Minimum	Maximum
CPMMA	0.074 ± 0.080	0.594	0.850
MPMMA	0.058 ± 0.052	0.514	0.688
3D 0°	0.059 ± 0.070	0.493	0.721
3D 45°	0.065 ± 0.075	0.544	0.800

Anova 1-way	Sum of square	df	Mean square	F	Sig.
Between groups	2.298	3	0.766	291.098	<0.001*
Within groups	0.621	236	0.003		
Total	2.920	239			

Post hoc tests	Mean difference	Std. error	Sig.
CPMMA-MPMMA	0.2405	0.0093	<0.001*
CPMMA-3D 0°	0.2383	0.0093	<0.001*
CPMMA-3D 45°	0.1493	0.0093	<0.001*
MPMMA-3D 0°	0.0022	0.0093	0.995
MPMMA-3D 45°	0.0912	0.0093	<0.001*
3D 0°–3D 45°	0.0890	0.0093	<0.001*

Note: *$p < 0.001$.

3.4. Analysis of dental arch fit across the study groups

Table 4 represents that the MPMMA group exhibited superior dental arch fit (0.058 ± 0.052) and minimal deviation compared to the study groups ($p < 0.001$). Both printed groups did not differ significantly from the control group. Furthermore, the groups produced with the 3D printer did not differ from one another in the best-fit evaluation. Reymus et al. [15] investigated the effect of print layer thickness on dimensional accuracy and related to fit accuracy, revealing that layers of 50 µm and 100 µm yield better precision than a 25 µm layer. They hypothesized that the enhanced light penetration of the thinner layer may cause over-curing, which could distort the final dimensions, as noted in the reference. Based on these findings and manufacturer recommendations, the present study selected a 100 µm layer thickness to optimize compatibility with the printing process and enhance fit accuracy. Unlike previous studies, this research found no statistically significant correlation between printed OC angle orientation and fit accuracy [11]. Consequently, future optimisation efforts could explore other factors influencing fit, including print resolution, material properties, support structure density, and curing protocol. Further investigation into these areas could enhance the precision and reliability of printed parts for applications demanding tight tolerances. Printing at a 0-degree orientation minimizes print time and maximizes accuracy due to the reduced number of layers [9]. In contrast, higher angles (60 degrees and above) increase print time because of the greater number of Z-axis layers, although they allow for more efficient use of the build plate, which may compromise accuracy [6,9]. Previous studies have shown that SLA-printed OC exhibit decreased accuracy and precision as the build orientation increases [23]. Specifically, researchers found that OC created with building angles below 60 degrees yielded higher accuracy compared to those produced at higher angles [23]. This current study focuses on a 45-degree orientation [9], which may enhance mechanical properties by optimizing the interaction between load direction and layer bonding [24]. This angle also allows for denser packing of OC compared to a 0-degree orientation. Earlier research suggests that a 45-degree orientation can contribute significantly to the mechanical properties of printed objects, highlighting the importance of load direction and layer bonding [24]. In our findings, the 0-degree orientation exhibited superior accuracy and fit for the OC groups compared to the 45-degree configuration. This improvement can be attributed to the alignment of print layers with the primary load-bearing directions, which minimizes interlayer defects and enhances dimensional stability. On the other hand, the 45-degree orientation introduces additional interlayer interfaces that may compromise the tightness and fit of the OCs. Anisotropic properties lead to orientation-dependent mechanical characteristics; therefore, 0-degree builds enhance stiffness and surface finish along the critical fit axis. Despite the potential for faster print times, the observed accuracy benefits suggest that minimizing layer interfaces with 0-degree builds outweighs the time savings for these occlusal devices.

Table 4. Analysis of dental arch fit across the study groups

Descriptive	Mean ± SD (mm)	Minimum	Maximum
CPMMA	0.036 ± 0.05	0.028	0.062
MPMMA	0.105 ± 0.052	0.652	0.131
3D 0°	0.041 ± 0.070	0.035	0.076
3D 45°	0.50 ± 0.075	0.041	0.087

Anova 1-way	Sum of square	df	Mean square	F	Sig.
Between groups	0.347	3	0.116	12.969	<0.001*
Within groups	2.104	236	0.009		
Total	2.451	239			

Post hoc tests	Mean difference	Std. error	Sig.
CPMMA-MPMMA	0.0990	0.0172	<0.001*
CPMMA-3D 0°	0.0151	0.0172	0.816
CPMMA-3D 45°	0.0273	0.0172	0.388
MPMMA-3D 0°	0.0839	0.0172	<0.001*
MPMMA-3D 45°	0.0717	0.0172	<0.001*
3D 0°–3D 45°	0.0122	0.0172	0.894

Note: *$p < 0.001$.

3.5. Therapeutic effects cores before treatment (BT) and after treatment (AT)

The chi-squared analysis results in Table 5 showed statistically significant improvements in the treatment group across all categories. Specifically, the treatment intervention led to a substantial and statistically significant reduction in reported pain during palpation, as well as a marked and statistically significant improvement in mandibular movement capabilities ($p < 0.001$). These findings indicate an overall improvement in jaw function following treatment. Furthermore, the analysis revealed that pain during movement also significantly decreased after treatment. This observed decrease in pain during movement was consistent across all groups assessed, with the statistical significance reaching a high level ($p < 0.001$). The consistent and statistically significant reductions in both palpation-induced and movement-related pain, coupled with improved mandibular movement, strongly suggest the treatment's effectiveness in improving jaw function and reducing pain. The preceding clinical investigation, as outlined in reference [25], utilized a follow-up period of three months, during which outcome assessments were based on observations conducted at the end of this designated timeframe. In contrast to this earlier methodology, the present study proposes that 3D-printed occlusal devices, in conjunction with conventional CAD-CAM fabricated appliances, can be utilized with a credible expectation of safety for an extended duration of up to six months, without inducing adverse complications.

Table 5. Functional examination scores taken before treatment (BT) and after treatment (AT)

		CPMMA		**MPMMA**		**3D 0°**		**3D 45°**	
		BT	**AT**	**BT**	**AT**	**BT**	**AT**	**BT**	**AT**
Palpation scores	Chi-Square	12,250	42,250	12,250	25,000	0,563	33,063	12,250	25,000
	df	1	1	1	1	1	1	1	1
	Asymp. Sig.	0.000	0.000	0.000	0.000	0.453	0.000	0.000	0.000
		CPMMA		**MPMMA**		**3D 0°**		**3D 45°**	
		BT	**AT**	**BT**	**AT**	**BT**	**AT**	**BT**	**AT**
Pain on movement	Chi-Square	2.250	49.000	9.000	45.000	18.063	45.563	12.000	45.563
	df	1	1	1	1	1	1	1	1
	Asymp. Sig.	0.134	0.000	0.003	0.000	0.000	0.000	0.000	0.000

3.6. Assessment of visual analog scale (VAS) scores before and after treatment

The analysis of participant-reported pain, measured using a Visual Analog Scale (VAS), demonstrated a statistically significant reduction in pain across all treatment groups following the intervention ($p < 0.001$). However, comparisons between groups revealed no statistically significant difference in pain reduction ($p < 0.001$; Table 6), indicating similar pain-relieving effects across all treatment methods. These findings suggest that 3D-printed OCs offer pain relief comparable to conventional treatments and can therefore be considered a valid and effective method of pain management. Previous studies found no link between participant satisfaction and the manufacturing technique [26,27]. In this study, participants evaluated their pain but were not asked about the comfort or ease of use of the occlusal devices. No additional feedback regarding patient satisfaction was collected. Future research should incorporate patient satisfaction into its assessments and explore alternatives, such as modified, thinner, lighter occlusal devices or different colour variations, to enhance patient comfort.

Table 6. Evaluation of the VAS values before and after the treatment

Paired samples test									
	Paired differences					**t**	**df**	**Significance**	
	Mean	**SD**	**Std. error mean**	**95% confidence interval of the difference**					
				Lower	**Upper**			**One-sided *p***	**Two-sided *p***
CPMMA BT-AT	5.500	1.080	0.342	4.727	6.273	16.102	9	<0.001*	<0.001*
MPMMA BT-AT	5.400	0.966	0.306	4.709	6.091	17.676	9	<0.001*	<0.001*
3D 0° BT-AT	5.400	0.966	0.306	4.709	6.091	17.676	9	<0.001*	<0.001*
3D 45° BT-AT	5.400	1.265	0.400	4.495	6.305	13.500	9	<0.001*	<0.001*

Note: *$p < 0.001$.

The limitation of using a single resin type is that variations in viscosity and curing properties across resins and manufacturers can affect results. Therefore, it is important to interpret results while considering the specific resin, printing parameters, printer, software, and analysis methods used; this prevents broad generalizations. Assessing the accuracy of 3D-printed OC is limited by resin selection, inconsistent measurement methods, and software variations. Standardized protocols for materials and measurement are needed for reliable assessments. Optimizing printing involves balancing performance with cost and time. This study didn't examine the time/cost of layer thickness or post-processing, nor did it assess water absorption, fatigue resistance, or bacterial adhesion, all vital for clinical outcomes. Future research should compare printers and different types of resins, evaluate printing orientations' impact, and clinically assess 3D-printed OC to improve surface finish, durability with a larger number of participants, and interlayer bonding.

4. Conclusions

Advances in digital technologies enable new occlusal device materials and production methods, requiring mechanical evaluation under bruxism. This study investigated the six-month clinical effects of 3D-printed occlusal devices—printing orientation, therapeutic outcomes, clinical performance (surface roughness, wear, antagonist tooth abrasion, device fit), and patient satisfaction—in patients. Material and printing orientation significantly affected surface texture; conventional PMMA had the roughest surface and greatest wear, while milled PMMA and 3D-printed PMMA were smoother. Among 3D-printed options, wear resistance improved, particularly in the orientation matching milled PMMA performance. After six months, antagonist tooth wear was highest in the control group and lowest at 0° orientation, demonstrating the importance of load direction. The 0° orientation consistently yielded the lowest wear, suggesting its suitability for patients with high occlusal loads. It is crucial to understand and mitigate anisotropy to optimize OC design, as these devices must endure functional loads while maintaining dimensional accuracy in clinical conditions.

Milled PMMA provided the best arch fit; 3D-printed groups showed comparable fits to the control group. All modalities offered therapeutic benefits, reducing pain and improving mandibular movement similarly, supporting the clinical viability of 3D-printed devices for TMD-related pain management. Material selection and printing orientation significantly impacted surface properties and clinical performance. Clinically, all treatments achieved comparable pain relief and improved function, indicating that 3D-printed occlusal devices are a viable alternative to conventional methods with appropriate printing parameters and post-processing. Future research should optimize print settings and assess long-term outcomes. Overall, 3D-printed occlusal devices performed as expected and are suitable for their intended use, offering a potentially effective treatment option with favorable mechanical characteristics. Nevertheless, further investigations involving a larger number of participants are necessary to substantiate and reinforce the conclusions drawn from the current research.

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Availability of Data and Materials: The data that support the findings of this study are available from the Corresponding Author, [Deger Ongul], upon reasonable request.

Ethics Approval: Ethical batch number TDK 2024/35910.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

OD	Occlusal devices
3D	3 Dimensional
AM	Additive manufacturing
SLA	Stereolithography
PMMA	Polymethyl methacrylate
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
TMD	Temporomandibular disorders
VA	Visual analog scale

References

1. van Lingen C, Tribst JPM. 3D-printed occlusal splints: a narrative literature review. J Adv Oral Res. 2025;16(1):25–33. doi:10.1177/23202068251317825.
2. Alqarawi FK. The influence of printing orientation on the properties of 3D-printed polymeric provisional dental restorations: a systematic review and meta-analysis. J Funct Biomater. 2025;16(8):278. doi:10.3390/jfb16080278.
3. Alharbi N, Wismeijer D, Osman R. Additive manufacturing techniques in prosthodontics: where do we currently stand? a critical review. Int J Prosthodont. 2017;30(5):474–84. doi:10.11607/ijp.5079.
4. Revilla-León M, Özcan M. Additive manufacturing technologies used for processing polymers: current status and potential application in prosthetic dentistry. J Prosthodont. 2019;28(2):146–58. doi:10.1111/jopr.12801.
5. Al Rashid A, Ahmed W, Khalid MY, Koç M. Vat photopolymerization of polymers and polymer composites: processes and applications. Addit Manuf. 2021;47(80):102279. doi:10.1016/j.addma.2021.102279.
6. Reymus M, Fabritius R, Keßler A, Hickel R, Edelhoff D, Stawarczyk B. Fracture load of 3D-printed fixed dental prostheses compared with milled and conventionally fabricated ones: the impact of resin material, build direction, post-curing, and artificial aging—an *in vitro* study. Clin Oral Investig. 2020;24(2):701–10. doi:10.1007/s00784-019-02952-7.
7. Orgev A, Levon JA, Chu TG, Morton D, Lin WS. The effects of manufacturing technologies on the surface accuracy of CAD-CAM occlusal splints. J Prosthodont. 2023;32(8):697–705. doi:10.1111/jopr.13610.
8. Revilla-León M, Cascos-Sánchez R, Zeitler JM, Barmak AB, Kois JC, Gómez-Polo M. Influence of print orientation and wet-dry storage time on the intaglio accuracy of additively manufactured occlusal devices. J Prosthet Dent. 2024;131(6):1226–34. doi:10.1016/j.prosdent.2022.12.005.
9. de Castro EF, Nima G, Rueggeberg FA, Araújo-Neto VG, Faraoni JJ, Palma-Dibb RG, et al. Effect of build orientation in gloss, roughness and color of 3D-printed resins for provisional indirect restorations. Dent Mater. 2023;39(7):e1–11. doi:10.1016/j.dental.2023.05.002.
10. Vasques MT, Laganá DC. Accuracy and Internal Fit of 3D printed Occlusal Splint, according to the printing position: a technique report. Clin Lab Res Dent. 2018:1–6. doi:10.11606/issn.2357-8041.clrd.2018.148012.

11. Cruz-Araújo SR, Sampaio-Fernandes MA, de Freitas BN, Simionato AA, Figueiral MH, Macedo AP. Accuracy of occlusal splints printed in different orientations by liquid crystal display technology: an *in vitro* study. J Dent. 2025;152:105461. doi:10.1016/j.jdent.2024.105461.
12. Ohrbach R, editor. Diagnostic criteria for temporomandibular disorders: assessment instruments [Internet]. [cited 2026 Jan 1]. Available from: https://inform-iadr.com/wp-content/uploads/2024/08/DC-TMD-Thai-Assessment-Instruments_2023_01_27.pdf.
13. Pecenek D, Gokcen-Rohlig B, Ongul D, Ayvalioglu DC. Evaluation of the clinical performance of different occlusal device materials. J Prosthet Dent. 2025;134(5):1806–12. doi:10.1016/j.prosdent.2024.04.021.
14. Väyrynen VOE, Tanner J, Vallittu PK. The anisotropicity of the flexural properties of an occlusal device material processed by stereolithography. J Prosthet Dent. 2016;116(5):811–7. doi:10.1016/j.prosdent.2016.03.018.
15. Reymus M, Lümkemann N, Stawarczyk B. 3D-printed material for temporary restorations: impact of print layer thickness and post-curing method on degree of conversion. Int J Comput Dent. 2019;22(3):231–7.
16. Taşın S, Ismatullaev A, Usumez A. Comparison of surface roughness and color stainability of 3-dimensionally printed interim prosthodontic material with conventionally fabricated and CAD-CAM milled materials. J Prosthet Dent. 2022;128(5):1094–101. doi:10.1016/j.prosdent.2021.01.027.
17. Ozer NE, Sahin Z, Yikici C, Duyan S, Ali Kilicarslan M. Bacterial adhesion to composite resins produced by additive and subtractive manufacturing. Odontology. 2024;112(2):460–71. doi:10.1007/s10266-023-00862-5.
18. Ribeiro AKC, de Freitas RFCP, de Carvalho IHG, de Miranda LM, da Silva NR, de Fátima D, et al. Flexural strength, surface roughness, micro-CT analysis, and microbiological adhesion of a 3D-printed temporary crown material. Clin Oral Investig. 2023;27(5):2207–20. doi:10.1007/s00784-023-04941-3.
19. Rizante FAP, Bombonatti JSF, Vasconcelos L, Porto TS, Teich S, Mondelli RFL. Influence of resin-coating agents on the roughness and color of composite resins. J Prosthet Dent. 2019;122(3):332.e1–5. doi:10.1016/j.prosdent.2019.05.011.
20. Zohdi N, Yang RC. Material anisotropy in additively manufactured polymers and polymer composites: a review. Polymers. 2021;13(19):3368. doi:10.3390/polym13193368.
21. Wulff J, Rauch A, Schmidt MB, Rosentritt M. Biaxial flexural strength of printed splint materials. Materials. 2024;17(5):1112. doi:10.3390/ma17051112.
22. Alqutaibi AY, Al-Gabri RS, Al-Zaghruri AS, Farghal AE, Alnazzawi AA, Alghauli MA. Clinical performance, accuracy, and physical-mechanical properties of 3D-printed removable partial denture metal frameworks compared with conventionally and partially digitally produced frameworks: a systematic review. J Prosthodont Res. 2026;70(2):206–23. doi:10.2186/jpr.jpr_d_25_00028.
23. Saadat Sarmadi B, Schmidt F, Beuer F, Metin DS, Simeon P, Nicic R, et al. The effect of build angle and artificial aging on the accuracy of SLA- and DLP-printed occlusal devices. Polymers. 2024;16(12):1714. doi:10.3390/polym16121714.
24. Unkovskiy A, Bui PH, Schille C, Geis-Gerstorfer J, Huettig F, Spintzyk S. Objects build orientation, positioning, and curing influence dimensional accuracy and flexural properties of stereolithographically printed resin. Dent Mater. 2018;34(12):e324–33. doi:10.1016/j.dental.2018.09.011.
25. Al-Moraissi EA, Conti PCR, Alyahya A, Alkebsi K, Elsharkawy A, Christidis N. The hierarchy of different treatments for myogenous temporomandibular disorders: a systematic review and network meta-analysis of randomized clinical trials. Oral Maxillofac Surg. 2022;26(4):519–33. doi:10.1007/s10006-021-01009-y.

26. Pho Duc JM, Hüning SV, Grossi ML. Parallel randomized controlled clinical trial in patients with temporomandibular disorders treated with a CAD/CAM versus a conventional stabilization splint. Int J Prosthodont. 2016;29(4):340–50. doi:10.11607/ijp.4711.
27. Berntsen C, Kleven M, Heian M, Hjortsjö C. Clinical comparison of conventional and additive manufactured stabilization splints. Acta Biomater Odontol Scand. 2018;4(1):81–9. doi:10.1080/23337931.2018.1497491.

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