

■ Research Article

Comparison of fracture resistance of occlusal splints fabricated by three manufacturing techniques: in-vitro study

Üç farklı üretim yöntemiyle üretilen okluzal splint materyallerinin kırılma dayanımlarının karşılaştırılması: in-vitro çalışma

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Abstract

Aim: This study aimed to compare the fracture resistance of occlusal splint materials fabricated using three different production methods.

Material and Methods: Digital designs of 10×10×2 mm blocks were prepared and fabricated using conventional, subtractive, and additive manufacturing (n=25). Supports were removed in all processes, and surface treatments were standardized. Fracture resistance tests were conducted using a universal testing machine with a 3 mm flat stainless steel compression tip at a loading speed of 1 mm/min. All tests were performed by the same operator under stable laboratory conditions. Maximum force at fracture was recorded in Newtons. Normality was assessed with the Shapiro Wilk test and intergroup differences were analyzed using the Kruskal-Wallis test followed by Bonferroni post hoc corrections ($\alpha=.05$).

Results: The subtractive manufacturing group showed the highest fracture resistance, followed by the additive and conventional groups ($P<0.05$).

Conclusion: Digital fabrication techniques demonstrated superior mechanical performance compared to the conventional method, especially in terms of fracture resistance and clinical durability.

Keywords: Occlusal splint, PMMA, CAD/CAM, Additive manufacturing, Subtractive manufacturing, Fracture strength

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Orcid: 0009-0007-5660-1656

Doi: 10.18663/tjcl.1780581

Received: 10.09.2025 Accepted: 28.09.2025

Öz

Amaç: Bu çalışmanın amacı, üç farklı üretim yöntemiyle hazırlanan oklüzal splint materyallerinin kırılma dayanımlarını karşılaştırmaktır.

Gereç ve Yöntemler: Dijital ortamda tasarlanan 10×10×2 mm boyutlarındaki örnekler; konvansiyonel (manuel olarak otopolimerizan akrilik ile), eksiltmeli (frezelenmiş PMMA bloklarla) ve eklemeli (DLP teknolojisiyle fotopolimer reçinelerden) yöntemlerle üretilmiştir (n=25). Her üretim sürecinde destek yapılar uzaklaştırılmış, yüzey işlemleri standart hale getirilmiştir. Kırılma dayanımı testleri, 3 mm çapındaki paslanmaz çelik düz kompresyon başlığı ve 1 mm/dk hızla çalışan universal test cihazı kullanılarak yapılmıştır. Tüm testler aynı operatör tarafından, sabit çevresel koşullarda gerçekleştirilmiştir. Maksimum kırılma kuvveti Newton cinsinden kaydedilmiştir. Veriler Shapiro-Wilk testi ile değerlendirilmiş, gruplar arası farklar Kruskal-Wallis testi ve Bonferroni düzeltmeleriyle analiz edilmiştir.

Bulgular: Eksiltmeli üretim yöntemi en yüksek kırılma dayanımını göstermiş, bunu eklemeli ve konvansiyonel yöntem izlemiştir (P<0.05).

Sonuç: Dijital üretim yöntemleri, konvansiyonel yöntemle kıyasla daha üstün mekanik performans sunmaktadır.

Anahtar kelimeler: Oklüzal splint, PMMA, CAD/CAM, Eklemeli üretim, Eksiltmeli üretim, Kırılma dayanımı

Introduction

Occlusal splints are frequently used in dentistry for the treatment of temporomandibular joint disorders, bruxism, and teeth clenching [1]. These appliances are designed to relax the masticatory muscles, protect the tooth surfaces, and reduce the forces on Temporomandibular joints (TMJs) [2]. For decades, splints have been fabricated manually using autopolymerizing polymethyl methacrylate (PMMA). However, the conventional production process is prone to human error [3]. Also, residual monomers may remain and lead to allergic reactions and other health concerns.

In recent years, digital manufacturing technologies have rapidly advanced. CAD/CAM systems and 3D printing technologies have enabled the production of highly precise and reproducible dental appliances, minimizing operator-related problems [4]. These systems, which offer patient-specific and high-precision outcomes in a shorter time compared to conventional methods, have established a new standard in prosthetic treatments in terms of both efficiency and quality [5]. Digital manufacturing approaches are generally classified into two main categories: subtractive and additive methods.

In the subtractive method, products are fabricated by milling pre-polymerized blocks, which enhances material homogeneity and provides higher mechanical strength [6]. This method minimizes the risk of deformation or shrinkage during the production process, thereby improving the fit of the restoration [7]. The blocks, produced under high pressure and controlled conditions. They ensure structural homogeneity, offering advantages in fracture resistance and longevity [8]. Additionally, reduced residual monomer levels during industrial production increase biocompatibility and

decrease adverse reactions in oral tissues [9]. Restorations manufactured by CAD/CAM systems exhibit smoother surfaces, reduce plaque retention and contribute positively to oral hygiene [10]. The rapid production time and chairside applicability of these methods shorten treatment durations and improve patient satisfaction [11]. Nevertheless, some limitations exist. One significant drawback is material waste, as a large portion of the milled block is discarded during the milling process [12]. Moreover, in complex geometries, the limited reach of the milling burs may result in insufficient detail reproduction [13]. The wear of milling tools over time can adversely affect surface quality and prolong production time [14]. Furthermore, the initial investment and operational costs of CAD/CAM systems are high. As the technology requires a certain level of expertise, user training and software proficiency are critical for effective utilization [15].

In contrast, 3D printers provide customized solutions through digital modeling and layer-by-layer production techniques, significantly reducing production time and minimizing material waste [16]. One of the prominent techniques among additive manufacturing methods is stereolithography (SLA), which uses light to cure liquid-based polymers. Similarly, digital light processing (DLP) technology operates on photopolymerization principles but allows faster production times.

Despite these technological advances, the clinical performance and durability of materials produced by different manufacturing methods still require comparative evaluation. In this context, comparing the physical properties of materials fabricated by different digital techniques plays a crucial role in determining the most appropriate method. This study aimed to examine the fracture resistance of acrylic occlusal splints fabricated by three

different manufacturing techniques. The study hypothesis was that the manufacturing technique would have no significant effect on the fracture resistance of the materials.

Material and Methods

In this study, 10×10×2 mm rectangular blocks were digitally designed (Figure 1) to evaluate the fracture resistance of PMMA samples fabricated by three different methods (n=25). Since it is an in vitro study, ethics committee approval is not required.

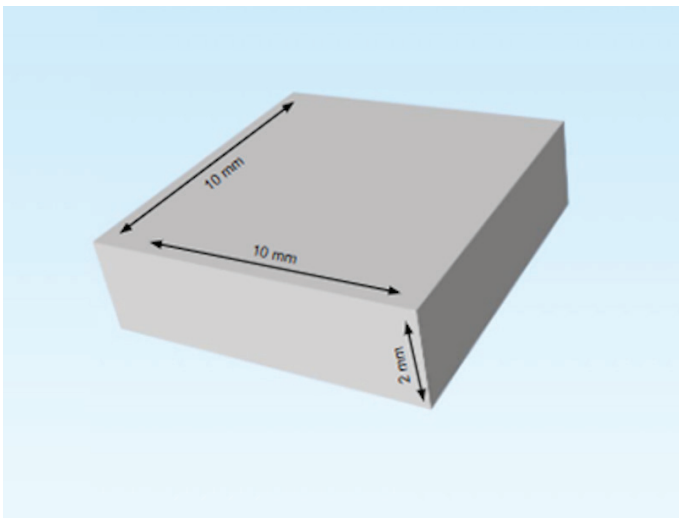


Figure 1. Sample digital design

For the conventional method involved several manual steps, following a carefully controlled protocol. Initially, standardized wax blocks (10×10×2 mm) were prepared using low-melting dental modeling wax (Polywax, Bilkim, China). These wax blocks were placed into metal flasks and invested with type III dental stone (Fujirock, GC Europe, Germany). The dental stone was mixed under vacuum and poured into the flasks on a vibrating table to avoid air entrapment. After setting for approximately 30 minutes, the flasks were immersed in a temperature-controlled boiling water bath for 10–15 minutes to eliminate the wax. Care was taken to control temperature and timing to prevent damage to the mold surfaces. Autopolymerizing acrylic resin (Akrodent, Koca Kimya, Turkey) was prepared according to manufacturer's instructions. Once the mixture reached a dough-like consistency, it was placed into the mold during the "packing stage." The mold was then closed and placed into a pressurized polymerization unit (Avrupa Dental, Turkey) at 60 psi and 45–50°C for 20 minutes to minimize porosities and enhance polymerization homogeneity. After polymerization, the molds were cooled to room temperature, opened, and the samples were carefully removed. Each sample was trimmed with 320-grit silicon carbide discs, followed by finer grinding with 400–600 grit abrasive papers. Finally, surfaces were polished using alumina-based polishing pastes

and low-speed polishers to minimize roughness and enhance gloss, aiding both esthetics and hygiene.

For subtractive manufacturing, the STL file generated during the digital design process was imported into CAD software (Exocad 3.0, exocad GmbH, Germany). Specimens were milled from PMMA block (20 mm, PMMA BioStar blocks, Germany) using a dry milling system (Roland DWX-52D, Roland DG Corporation, Japan) at up to 60,000 rpm. Supports were removed manually by the same operator; no additional finishing or polishing was applied.

For additive manufacturing, the STL file was imported into Exocad 3.0, and samples were printed using SLA technology (Formlabs, USA) at a 0° orientation parallel to the platform. Supports generated by the software were retained, and a layer thickness of 100 µm was set. After printing, the samples were cleaned in an ultrasonic bath (iSonic, USA) with isopropyl alcohol for 5 minutes, removed from the platform, and cured on both sides for 3 minutes using a UV curing unit (3M ESPE, USA).

Before testing, all samples were stored at room temperature for 24 hours to stabilize mechanical properties and allow any residual polymerization reactions to complete. Fracture resistance testing was conducted using a universal testing machine (Lloyd LR50K Plus, AMETEK®, UK) (Figure 2). Samples were placed on the fixed lower platform, and a 3 mm stainless steel compression tip applied load perpendicularly to the occlusal surface at a speed of 1 mm/min. The maximum fracture load (N) was recorded via computer software.

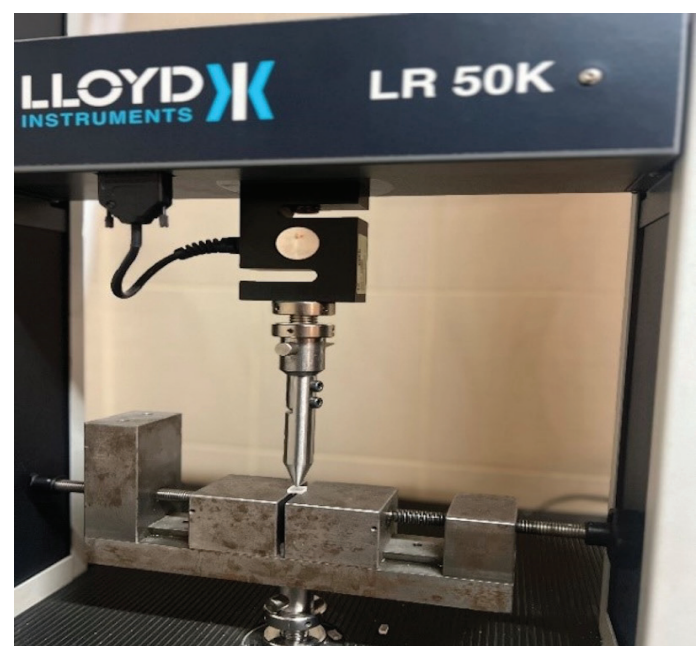


Figure 2. The specimens were subjected to testing in a universal testing machine

The Shapiro-Wilk test was used to assess normality. Since the data did not follow a normal distribution, the Kruskal-Wallis test was applied for comparison among three or more independent groups, followed by Bonferroni-adjusted post hoc tests using. The statistical analysis was performed by using a software (IBM SPSS Statistic v25, IBM Corp and Rv3.4; R Foundation) ($\alpha=.05$).

Results

The fracture resistance values of occlusal splint materials fabricated using three different methods are listed in Table 1. Samples fabricated by the subtractive manufacturing showed the highest fracture resistance, followed by the additive manufacturing and the conventional method ($P < 0.05$) (Figure 3).

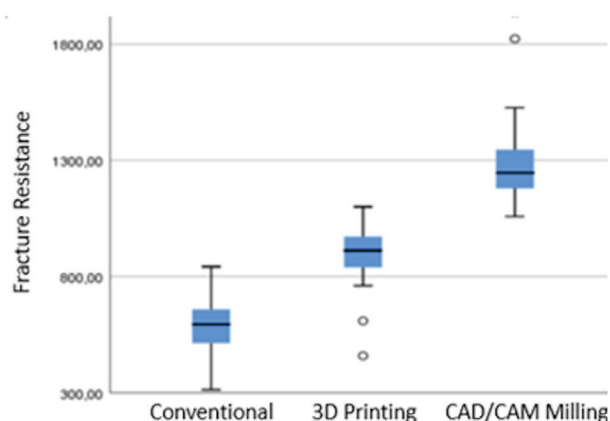


Figure 3. Box plot showing the distribution of fracture resistance values according to the production methods

Table 1. Fracture resistance of occlusal splint materials manufactured by three different methods

Production Method	Median (Min-Max)	P*
Conventional	594 (313–841)	<0.001
Additive (3D Printing)	912 (459–1100)	
Subtractive (Milling)	1246 (1058–1930)	

* $p < 0.05$. Values with different superscript letters indicate statistically significant differences.

Discussion

In this study comparing the fracture resistance of occlusal splint materials fabricated by conventional, additive, and subtractive manufacturing, statistically significant differences were observed among the groups ($P < 0.001$). Therefore, the null hypothesis that the manufacturing technique would have no effect on fracture resistance was rejected.

Prpić et al. [1] reported that dental structures fabricated by digital techniques exhibited superior mechanical strength compared to conventional methods. These findings are consistent with our results, which demonstrate greater resistance in splints fabricated by subtractive and additive manufacturing. Zhang et al. [3] stated that the layer-by-layer structure of 3D printing reduces internal voids and improves material homogeneity. Similarly, Barbur et al. [2] emphasized that such structures provide greater durability under high stress. García et al. [4] suggested that occlusal splints fabricated with CAD/CAM systems are mechanically more durable due to the use of standardized PMMA blocks, although microscopic abrasions during milling may slightly affect strength. Conversely, errors and air bubbles during the conventional production process can adversely affect fracture resistance [4]. Singh et al. [5] also noted that porosities generated during manual processing could lead to mechanical failures.

Digital manufacturing offers not only mechanical advantages but also clinical benefits such as reduced production time, fewer human errors, and customization [2,6]. Sánchez-Monescillo et al. [6] highlighted the long-term durability and reliability of digitally fabricated dental appliances under high stress. Patel et al. [7] found that splints fabricated by additive and subtractive manufacturing exhibited significantly higher fracture resistance than those fabricated by conventional method. These results are consistent with ours. Eftekhari et al. [8] noted the cost-effectiveness, reproducibility, and environmental sustainability of digital methods. Nguyen et al. [10] argued that more researchs are needed on the long-term biological and mechanical performance of digital production methods. Our study suggests that additive manufacturing offers a promising alternative in fabrication of occlusal splints, while subtractive manufacturing remains valuable for cases requiring high precision.

One limitation of this study is that the samples were not fabricated in clinically used occlusal splint shapes but rather as standard square blocks. Additionally, the samples were not subjected to dynamic loading in a chewing simulator, thermal cycling, or artificial aging. Future in-vivo and in-vitro studies are needed to evaluate fracture resistance of clinically shaped splints produced by additive and subtractive techniques after aging. Further research should also focus on the clinical long-term effects and durability of these manufacturing approaches. Material selection plays a crucial role in the mechanical performance of occlusal splints [9].

Conclusion

Within the limitations of this study, the following conclusions can be drawn:

1. Samples fabricated by the subtractive manufacturing exhibited the highest fracture resistance values, followed by the additive manufacturing and the conventional method.
2. Digital fabrication techniques demonstrated superior mechanical performance compared to conventional methods and show promising potential for clinical application.

Conflict of interest

The authors declare no conflict of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements

The authors would like to thank the laboratory staff who contributed to the execution of this study.

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