Wear Evaluation of Different Occlusal Splints and Fixed Prosthodontics Restorations

Angham I. El-Gendy, BDS, MDS[1]**, Mahmoud Shakal,** BDS, MDS, PHD[2]**,**
Fatma A. Hasaneen, BDS, MDS, PHD[3]

ArticleHistory:Received:12.02.2022 **Revised:**29.03.2023 **Accepted:**15.04.2023

Abstract

Purpose: The purpose of this in vitro study was to evaluate the wear of different occlusal splints and opposing fixed restorations.
Methods: Three different occlusal splints with two different antagonists were used (n=10). A full dentate typodont was used with an occlusal splinton the upper arch opposing crowns on lower posterior molars either porcelain fused to metal (PFM) or veneered polyetheretherketone (PEEK). Group I: 3D printed occlusal splint Group II: Heat-cured occlusal splint Group III:vacuum-formed occlusal splint. All specimens were tested by chewing simulator including the application of (50N) load for 75,000 cycles to simulate 6 months. Surface roughness and volume loss of all specimens were measured using an optical profilometry before and after the chewing simulation.Descriptive statistics, Student t-test and one-way ANOVA were done.Pearson's correlation was done between volume loss and roughness change.
Results: 3D printed group recorded the lowest surface roughness change and volume loss ($p \leq 0.0001$, $p=0.0013<0.05$). Total volume loss against PFM was statistically significantly higher than the volume loss against PEEK ($p=0.014< 0.05$). Pearson linear showed that there was a weak positive relation between surface roughness and volume loss.
Conclusion: 3D printed occlusal splints are more wear-resistant after wear simulation for 6 months. The effect of the antagonist on the wear of the splint could be considered as PFM causing more wear on the splint than the PEEK.
Clinical significance: Using 3D-printing technology in production of occlusal splints can improve wear resistance of the occlusal splints made for bruxers especially those with PFM restorations.
Keywords: Bruxism, Occlusal Splints, fixed prosthodontics.

1. Assistant Lecturer, Department of fixed prosthodontics, College of Dentistry, University of Tanta, Tanta, Egypt.
2. Professor, Department of fixed prosthodontics, College of Dentistry, University of Tanta, Tanta, Egypt.
3. Lecturer, Department of fixed prosthodontics, College of Dentistry, University of Tanta, Tanta, Egypt.

Corresponding author: Angham I. El-Gendy **E-mail:** anghamelgndy@outlook.com

DOI: 10.31838/ecb/2023.12.4.087

INTRODUCTION

Bruxism is the grinding or clenching of teeth for reasons other than swallowing or eating, and it can be divided into two types: sleep bruxism and awake bruxism.(1) It is commonly linked with tooth abrasions and mobility, dental restoration fractures, masseter muscle hypertrophy, and myalgia or arthralgia, all of which are symptoms of temporomandibular disorders (TMD). The cause of bruxism is unknown, but etiological variables like as stress, neurological illnesses, certain medicines, and occlusal interferences have been reported.(2)

Physiotherapy, occlusal splints, medication injections, arthroscopy, and surgery are the most common treatments.(3) The entire occlusal splint manufacturing process was done manually. Recently, (Computer-Aided-Design / Computer-Aided-Manufacture) CAD/CAM was utilized to produce the occlusal device by subtractive or additive techniques.(4) When compared to the traditional gold standard, this would have various advantages such as superior fit, biocompatibility, and dimensional stability.(5)

Restorative materials should ideally wear at the same ratio as posterior tooth enamel, which is between 20-

40 µm per year(6). The surface roughness is a concern as it could affect plaqueaccumulation, staining, and wear of opposing natural teeth and materials.(7) The wear of the restorative material's occlusal surface can affect the thickness of the occlusal part of therestoration and the opposing structure, which can result in occlusion changes, unstable occlusal contacts due to wear facets creation leading to a decrease in the appliance's longevity.(8)
Porcelain fused to metal (PFM) was the most common restoration as it offers a stronger restoration while also being aesthetically pleasing. Also, highly resistant to wear, however, roughness of the porcelain cause wear of opposing natural teeth or restorations.(9)Modified Polyetheretherketone (PEEK) had found to have outstanding biocompatibility and elastic behavior comparable to that of bone. It might be manufactured using either CAD/CAM or compression molding techniques. Because modified PEEK has a pearl-white opaque color, it requires veneering. (10)
Because clinical wear evaluation is more expensive, required more time, and is methodologically challenging, masticatory simulators have been developed to simulate the oral environment and create wear in test specimens.(11) The chewing simulator has been utilized in in-vitro research to measure the two-body wear resistance of various materials.(12) Few studies had tested the wear of different occlusal splints with the natural tooth,(13) composite resin(14) or steel ball(15) antagonist. So, the purpose of this study was to evaluate the wear of different occlusal splints opposing fixed prosthodontics restorations. The null hypothesis was that there would be no difference in wear resistance of occlusal splints fabricated by different methods.

MATERIALS AND METHODS

This study was carried out as controlled experimental study. The experimental study was carried out at Fixed Prosthodontics Department, Faculty of Dentistry, Tanta University. The total sample size in this study was $60\ samples$, 10 sample in each group. Each group had an occlusal splint (PolyMethylMetha Acrylate (PMMA)) on the upper arch opposing porcelain fused to metal (PFM) and PolyEther Ether Keton (PEEK) crowns on the lower posterior molars on a typodonte (Ramses, Egypt)(n=10):
Group I:3D printed occlusal splint (Dental yellow clear, Harz lab, Moscow, Russia).
Group II:Heat-cured occlusal splint (Rapid simplified heat cured clear acrylic resin, Vertex-Dental bv, The Netherland).
Group III:vacuum-formed occlusal splint (CRYSTAL PLATE 2,0 mm- PET-G, Bio art, 2BBrazil).
The design of the splint was standardized as: the occlusal thickness was 2 mm posteriorly, 1 mm labially and the splint was extended to cover the incisal third labially and palatally to the cervical area.(16)
For the vacuum-formed splints, upper arch impressions were made with irreversible hydrocolloid (Cavex cream alginate, Cavex Holland BV) then pouring was done with hard die stone (Hard Rock, Stone; Whip Mix, Corp, Louisville, USA). Two thermoplastic sheets with 2mm thickness were used with cold cure acrylic monomer applied in between them using a brush for bonding (Dr. Amr Elkmaah design). Then splints were adjusted on the cast to the desired extension. (16)For the heat-cured splint, a wax pattern with the desired thickness and extension was done on the maxillary cast to be replaced by the heat-cured acryl. Polymerization was done by the pressing technique. Then deflasking, finishing ,and polishing were done.(17)
For the 3D-printed occlusal splint Scanning was done by using a digital scanner (Ceramill 400 digital scanner, Amman Girrbach, Germany). The designing was done by Exo Cad software (Exo Cad 2019, Gmbh, Germany) and then saved as an STL file.The slicing software (Form Ware B.V., Amsterdam, The Netherland) of the 3D printer (RASDENT 3D Printer Model S RASPART) was used to convert the CAD STL file of the resin into a G-code. The sliced file was sent to the 3D printer via the internet then 3D printing was done by Stereolithography. All types of splints were cleaned with isopropyl alcohol and then finished and polished by using a disc on a rotary machine under wet condition. Finally, steam cleaning was done and washing in ultrasonic at room temperature for 10 minutes.
Teeth no 36, 37, 38, 46, 47, and 48 (according to FDI) were used as abutments.A silicone putty index (Express STD firmer set, 3M ESPE, St.Paul, MN USA) of the tooth was done before tooth preparation to check the amount of tooth reduction and help in standardization of the thickness of the veneering material. The occlusal reduction was 1.5 mm on the nonfunctional cusp and 2mm on the functional cusp. A deep chamfer finish line with axial reduction of 1.2 mm. for PFM crowns, while 1 mm wide shoulder finish line for PEEK crowns.
Each abutment was scanned then the coping was designed with 0.5 mm thickness. The coping design was 3d printed by using Castable resin (EPAX Castable Resin, EPAX, North Carolina, United

States) then soaking the copings in isopropanol for 20 minutes, and excess resin was removed.post-polymerization was done for the copings for 60 minutes after cleaning. Metal coping was fabricated by using the lost wax technique: spruing, investment, burn out, casting ,and finishing to receive the porcelain. Preparation of metal copings was done then porcelain application and glazing.Dry milling was done by five-axis milling machine (DWX-52D 5-Axis Dental Milling Machine, Roland, DGSHAPE, North America). PEEK (Bre CAM BioHPP, Bredent, GmbH & Co. KG, Germany)specimens milled copings were veneered using vacuum formed index with Visio.Lign system (Bredent, GmbH & Co. KG, Germany).

Sandblasting was done with aluminum oxide powder (Al2O3) on all the crowns. Cementation was done with the aid of a custom-made cementing device with a 5 kg load application using glass ionomer cement (Medicem, Promedica Dental Material GmbH, Neumuenster, Germany) according to the manufacturer's recommendations.

Two-body wear test was performed using a chewing simulator (ROBOTA chewing simulator Model ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., Germany). 50 Newton force was exerted for 75000 cycles to simulate 6 months(18) with vertical movement of 1mm, horizontal movement of 3mm ,and 1.6Hz frequency.

Surface roughness and volume loss were measured before and after wear simulation through optical profilometry. Specimens were photographed using a USB Digital microscope (Scope Capture Digital Microscope, Guangdong, China). Analyzing was done with WSxM software (Ver 5 develop 4.1, Nanotec, Electronica, SL, Madrid, Spain)as shown in Figures.1 to calculate the average of heights (Ra) expressed in µm and volume loss expressed in mm^3.(19),(20)

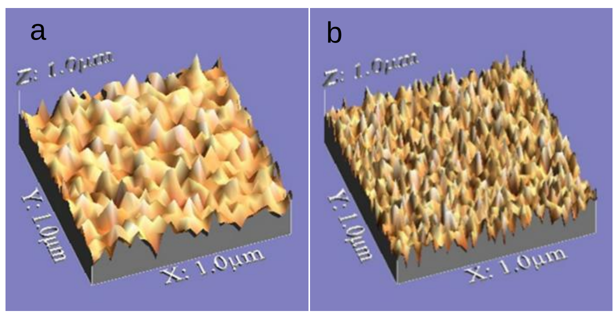

Figure 1. Surface topography of the splint surface showing surface roughness before (a) and (b) after chewing simulator.

STATISTICAL ANALYSIS

This was done by (InStat 3; Graph Pad Inc) as follows: descriptive statistics for each group results, Student t-test was done between mean groups before and after wear simulation results and One-way ANOVA followed by Tukey's post-hoc (if showed significance) was performed between wear changes. Pearson's correlation was done between volume loss and roughness change.

RESULTS

The difference in roughness changes recorded between groups against PEEK andPFM were statistically significant as indicated by ANOVA test ($p \leq 0.0001 < 0.05$) with heat-cured recorded the highest change mean value(0.0102µm),(0.0166µm) respectively.

Total roughness change regardless of splint type against PFM was statistically non-significant higher than the change mean value against PEEK as confirmed by unpaired t-test ($p=0.4435 > 0.05$) as shown in **Table 1.**

Total roughness change of PFM against different splint materials was statistically non-significant higher than the change mean value of PEEK as confirmed by unpaired t-test ($p=0.064 > 0.05$).

The difference in volume loss recorded between splint groups against PEEK was statisticallynon-significant($p=0.6984 > 0.05$)and against PFM was statisticallysignificantas indicated by ANOVA test ($p=0.0013 < 0.05$)with the 3D-printedgroup recorded the lowestvolume loss mean value(-0.002 mm^3),(-0.00154 mm^3)respectively.

Total volume loss against PFM was statistically significantly higher than mean value against PEEK as confirmed by unpaired t-test ($p=0.014 < 0.05$) as shown in **Table2.**

Total volume change in PEEK crowns was statistically non-significant higher than the change

mean value in PFM crowns against splint material as confirmed by unpaired t-test (p=0.0853> 0.05).
It was found that there wasa weak positive correlation between volume loss (mm^3) and roughness change (µm) as indicated by Pearson linear correlation (Correlation coefficient (r) = 0.1234, r^2= 0.0152 and p > 0.05) as shown in **Table 3.**

Table 1. Comparison between mean values and standard deviations (SD) for roughness change results (µm) for all splint materials against PEEK vs. PFM after 6 months wear simulation cycles.

		Change		Statistics
		PEEK antagonist	**PFM antagonist**	**P value**
Gr_I	**Mean**	0.0033	0.0026	0.0555 ns
	SD	0.0013	0.0006	
Gr_II	**Mean**	0.0102	0.0166	<0.0001*
	SD	0.0039	0.0004	
Gr_III	**Mean**	0.0066	0.0014	<0.0001*
	SD	0.0018	0.0005	

*; significant (p≤0.05) ns; non-significant (p>0.05)

Table 2. Comparison between (mean values ±SD) for volume loss results (mm^3) for all splint materials against PEEK vs. PFM after 6 months wear simulation cycles

		Volume loss		Statistics
		PEEK antagonist	**PFM antagonist**	**P value**
Gr_I	**Mean**	-0.002	-0.00154	0.7747 ns
	SD	0.0024	0.00111	
Gr_II	**Mean**	-0.00223	-0.00283	0.3457 ns
	SD	0.001931	0.000318	
Gr_III	**Mean**	-0.0025	-0.00354	0.092 ns
	SD	0.001082	0.001511	
Statistics	**P value**	0.6984 ns	0.0013*	

*; significant (p<0.05) ns; non-significant (p>0.05)

Table 3. Linear correlation between volume loss (mm^3) and roughness change (µm).

Parameter	Correlation coefficient (r)	r^2	P value
Volume loss (mm^3)	0.1234	0.0152	0.8158 ns
Roughness change (µm)			

DISCUSSION

The null hypothesis was rejected as the 3D-printed occlusal splint was found to have the least wear change among the other types of splint. Occlusal splints are considered the main element in the treatment of bruxism and TMJ disorders. Hard splints could be an indication when there is a need to decrease tooth wear and protect the restorations. However, little information is available on the wear of teeth or restorations caused by contact with different splint materials and fabrication techniques.(21)
Wear limits the appliance's lifetime by preventing the equilibration of occlusal contacts. This could result in a negative effect on treatment outcomes and the requirement for better-suited materials.(22)
The uniqueness of the current study was using a typodont, with artificial upper and lower arch full dentate. This geometry may allow similarity to the aspect that exists in the mouth when dental materials

wear out during function. As it was found that flat samples were shown more wear than crown-shaped samples.(23)

In this study three upper different splints were used, vacuum-formed splints were fabricated as they had the advantages of ease of fabrication and cheapness. The second one was the most common manufacturing material, conventional heat-cured acrylics. Because of its good biocompatibility, less expensive, easy processed ,and has high strength.(24)With the introduction of CAD/CAM in dentistry, additive manufacturing (AM);(25) 3D-printed occlusal splints were fabricated. They had the advantages of being less time-consuming, low shrinkage ,and a more homogenous products.(26)

All splints were stored for two weeks in distilled water at 25 °C before testing to avoid water sorption of heat cured that occurs during clinical use to produce water balance to compensate for material shrinkage.(27)All Tested materials received a polishing procedure to reach a similar degree of baseline surface roughness. This was suggested by Amer et al(28) who recommended standardization of the initial roughness (Ra).

In this study chewing simulator was used by setting the occlusal bruxial force to 50 Newton for 75000 cycles to simulate 6 months.(18) This was accompanied by continuous washing with demineralized water at 30 C(13) to remove abraded particles which could reduce the coefficient of friction and decrease the wear.(29) Many previous studies(15),(30),(13),(22),(31) had used an average force of 49 to 50 N which would be equal to a single point contact. On average, it was recommended to wear occlusal devices from 1 to 12 months with continuous follow-ups.(12)

The heat-cured splint was found to have the highest surface roughness change which was significantly higher than the other two types of splint ($p \leq 0.0001 < 0.05$). This may be due to the release of residual monomer, which could affect its dimensional stability and could result in porosity that increases surface roughness. (32) These results were supported by the findings of two studies(32),(33) with the conventional heat-polymerized had higher surface roughness values.

However, a study(34) compared the surface roughness of PMMA produced by heat-cured and CAD/CAM reported that higher roughness was for the CAD/CAM splint. This may be due to milling out from blanks, hand finished then cutting of the pre-polymerized specimen which could result in additional surface roughness and internal tensions in the resin, which wouldn't be in the conventional specimen.

The total volume loss of splint material against PFM crowns was significantly higher than that against PEEK crowns as feldspathic porcelains had low toughness and had leucite crystals that were liable to fatigue so wear could initiate cracks. Repeated loading will lead to cracks propagation and material loss that could accelerate the wearing of the opposing resulting in a rough and abrasive surfaces.(35)

The 3D-printed and vacuum-formed splints were found to have the lowest comparable surface roughness change. This difference may be due to the fabrication process that could result in different degrees of conversion and cross-linked densities of the polymers. These findings were supported by a previous study(8) showed that vacuum-formed, additive ,and subtractive occlusal splints showed comparable results. Another study(36) measured the surface roughness of different occlusal splint materials and showed that vacuum-formed had comparable surface roughness with other types of splint.

According to the finding of this study, the 3D printed occlusal splint had shown to have the least wear loss which might be due to less polymerization shrinkage, less residual monomer content, less porosity ,and less manual error. Reyes-Sevilla et al.(14) concluded that printed PMMA and polyamide-based splints exhibited less wear than the chemical-cured or milled PMMA splints which was matching with the result of this study.On the contrary, another study(30) that evaluated wear of 3D-printed, milled ,and heat-cured PMMA occlusal splints found that the lowest wear resistance was the 3D-printed splint, this may be due to difference in the specimen geometry as they used a crown-like coping occlusal device and cemented it on tapered metal alloy abutment. Another difference was the printer as they used a DLP printer as it was found that the flexure strength was highest in SLA printed occlusal devices with vertical printing direction.(37) Also they used the replica technique for wear measurement and the cycles were set to reach 120,000 cycles.

The results of wear and surface roughness for tested splint materials in the current study showed that the increase in surface roughness could lead to more volume loss as found in a previous study.(22) The coefficient of friction, which increased by surface roughness, had been reported to result in greater wear of the antagonist.(38)

The limitations of this study were: first, it was done as an in vitro study. Clinically, corrosive wear is important. Water, resin ,and alcohol could lead to the leaching of filler, and some microorganisms could cause resin degradation.(39) Another limitation was the lack of saliva in the chewing simulation, so it was recommended to artificial saliva incorporation in the chewing simulator ,and exposure of the specimens to an exogenous chemical substances during the chewing simulation to investigate the corrosive wear aspect. Limited studies were available on 3D-printed occlusal device materials so further investigation was recommended, especially on printing build angles and settings.

CONCLUSION

According to the finding of this study and within its limitation of this study, it was found that:

1. 3D-printed occlusal splints have the least wear change after wear simulation for 6 months when compared with heat-cured and vacuum-formed occlusal splints.
2. PFM crowns produce more wear on the opposing splint surface.

Conflict of interest:

None of the authors have any conflict of interest.

REFERENCES

1. Lobbezoo F, Ahlberg J, Raphael KG, Wetselaar P, Glaros AG, Kato T, et al. International consensus on the assessment of bruxism: Report of a work in progress. J Oral Rehabil. 2018;45(11):837–44.
2. Fernández-Núñez T, Amghar-Maach S, Gay-Escoda C. Efficacy of botulinum toxin in the treatment of bruxism: Systematic review. Med Oral Patol Oral y Cir Bucal. 2019;24(4):416–24.
3. Gremillion HA, Klasser GD. Temporomandibular disorders: A translational approach from basic science to clinical applicability. 2017:1–217.
4. Waldecker M, Leckel M, Rammelsberg P, Bömicke W. Fully digital fabrication of an occlusal device using an intraoral scanner and 3D printing: A dental technique. J Prosthet Dent [Internet]. 2019;121(4):576–80. Available from: https://doi.org/10.1016/j.prosdent.2018.09.021
5. Dedem P, Türp JC. Digital Michigan splint - from intraoral scanning to plasterless manufacturing. Int J Comput Dent [Internet]. 2016;19(1):63–76. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27027103
6. Albashaireh ZSM, Ghazal M, Kern M. Two-body wear of different ceramic materials opposed to zirconia ceramic. J Prosthet Dent [Internet]. 2010;104(2):105–13. Available from: http://dx.doi.org/10.1016/S0022-3913(10)60102-3
7. Naumova EA, Schneider S, Arnold WH, Piwowarczyk A. Wear behavior of ceramic CAD/CAM crowns and natural antagonists. Materials (Basel). 2017;10(3):1–13.
8. Huettig F, Kustermann A, Kuscu E, Geis-Gerstorfer J, Spintzyk S. Polishability and wear resistance of splint material for oral appliances produced with conventional, subtractive, and additive manufacturing. J Mech Behav Biomed Mater [Internet]. 2017;75(June):175–9. Available from: https://doi.org/10.1016/j.jmbbm.2017.07.019
9. Weigl P, Saarepera K, Hinrikus K, Wu Y, Trimpou G, Lorenz J. Screw-retained monolithic zirconia vs. cemented porcelain-fused-to-metal implant crowns: a prospective randomized clinical trial in split-mouth design. Clin Oral Investig. 2019;23(3):1067–75.
10. Tekin S, Cangül S, Adıgüzel Ö, Değer Y. Areas for use of PEEK material in dentistry. Int Dent Res. 2018;8(2):84–92.
11. Heintze SD, Cavalleri A, Forjanic M, Zellweger G, Rousson V. Wear of ceramic and antagonist-A systematic evaluation of influencing factors in vitro. Dent Mater. 2008;24(4):433–49.
12. Ghazal M, Kern M. Wear of human enamel and nano-filled composite resin denture teeth under different loading forces. J Oral Rehabil. 2009;36(1):58–64.
13. Domanic KY, Aslan YU, Ozkan Y. Two-body wear of occlusal splint materials against different antagonists. BMC Oral Health. 2020;20(1):1-7.
14. Reyes-Sevilla M, Kuijs RH, Werner A, Kleverlaan CJ, Lobbezoo F. Comparison of wear between occlusal splint materials and resin composite materials. J Oral Rehabil. 2018;45(7):539–44.
15. Kurt H, Erdelt KJ, Cilingir A, Mumcu E, Sülün T, Tuncer N, et al. Two-body wear of occlusal splint materials. J Oral Rehabil. 2012;39(8):584–90.
16. Vasques MT, Mori M, Laganá DC. Three-dimensional printing of occlusal devices for temporomandibular disorders by using a free CAD software program: A technical report. J Prosthet Dent. 2020;123(2):232-35
17. Grymak A, Waddell JN, Aarts JM, Ma S, Choi JJE. Evaluation of wear behaviour of

various occlusal splint materials and manufacturing processes. J Mech Behav Biomed Mater [Internet]. 2022;126(1):105053. Available from: https://doi.org/10.1016/j.jmbbm.2021.105053

18. Rosentritt M, Behr M, van der Zel JM, Feilzer AJ. Approach for valuating the influence of laboratory simulation. Dent Mater. 2009;25(3):348–52.
19. Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. J Mater Sci Mater Med. 2007;18(1):155–63.
20. Lohbauer U, Reich S. Antagonist wear of monolithic zirconia crowns after 2 years. Clin Oral Investig. 2017;21(4):1165-72.
21. Osiewicz MA, Werner A, Roeters FJM, Kleverlaan CJ. Effects of occlusal splint therapy on opposing tooth tissues, filling materials and restorations. J Oral Rehabil. 2021;48(10):1129-34.
22. Benli M, Eker Gümüş B, Kahraman Y, Gökçen-Rohlig B, Evlioğlu G, Huck O, et al. Surface roughness and wear behavior of occlusal splint materials made of contemporary and high-performance polymers. Odontology. 2020;108(2):240-50.
23. Wimmer T, Huffmann AMS, Eichberger M, Schmidlin PR, Stawarczyk B. Two-body wear rate of PEEK, CAD/CAM resin composite and PMMA: Effect of specimen geometries, antagonist materials and test set-up configuration. Dent Mater. 2016;32(6):127–36.
24. de Souza Leão R, Maior JRS, de Araújo Lemos CA, do Egito Vasconcelos BC, Montes MAJR, Pellizzer EP, et al. Complications with PMMA compared with other materials used in cranioplasty: a systematic review and meta-analysis. Braz Oral Res. 2018;32(7):31.
25. Pillai S, Upadhyay A, Khayambashi P, Farooq I, Sabri H, Tarar M, et al. Dental 3d-printing: Transferring art from the laboratories to the clinics. Polymers. 2021;13(1):157.
26. Occlusal C a DC a M, Dunn BDB, Hons BDS, Lewis MB, Pros D, Pros M. CAD/CAM Occlusal splints : A new paradigm. Australasian Dental Practice. Australas Dent Pract. 2011;22(4): 130–33.
27. Grymak A, Aarts JM, Ma S, Waddell JN, Eun Choi JJ. Comparison of hardness and polishability of various occlusal splint materials. J Mech Behav Biomed Mater. 2021;115(1):10470.
28. Amer R, Kürklü D, Johnston W. Effect of simulated mastication on the surface roughness of three ceramic systems. J Prosthet Dent. 2015;114(2):260-65.
29. Heintze SD, Reichl FX, Hickel R. Wear of dental materials: Clinical significance and laboratory wear simulation methods —A review. DentMater J. 2019;38(3):343-53.
30. Lutz AM, Hampe R, Roos M, Lümkemann N, Eichberger M, Stawarczyk B. Fracture resistance and 2-body wear of 3-dimensional–printed occlusal devices. J Prosthet Dent. 2019;121(1):166-72.
31. Wesemann C, Spies BC, Sterzenbach G, Beuer F, Kohal R, Wemken G, et al. Polymers for conventional, subtractive, and additive manufacturing of occlusal devices differ in hardness and flexural properties but not in wear resistance. Dent Mater. 2021;37(3):432-42.
32. de Oliveira Limírio JPJ, Gomes JM de L, Alves Rezende MCR, Lemos CAA, Rosa CDDRD, Pellizzer EP. Mechanical properties of polymethyl methacrylate as a denture base: Conventional versus CAD-CAM resin – A systematic review and meta-analysis of in vitro studies. J Prosthet Dent. online 2021.
33. Al-Dwairi ZN, Tahboub KY, Baba NZ, Goodacre CJ, Özcan M. A Comparison of the Surface Properties of CAD/CAM and Conventional Polymethylmethacrylate (PMMA). J Prosthodont. 2019;28(4):452-57.
34. Srinivasan M, Gjengedal H, Cattani-Lorente M, Moussa M, Durual S, Schimmel M, et al. CAD/CAM milled complete removable dental prostheses: An in vitro evaluation of biocompatibility, mechanical properties, and surface roughness. Dent Mater J. 2018;37(4):207.
35. Oh WS, DeLong R, Anusavice KJ. Factors affecting enamel and ceramic wear: A literature review. J Prosthet Dent. 2002;87(4):451-59.
36. Benli M, Eker Gümüş B, Kahraman Y, Gökçen-Rohlig B, Evlioğlu G, Huck O, et al. Surface roughness and wear behavior of occlusal splint materials made of contemporary and high-performance polymers. Odontology [Internet]. 2020;108(2):240–50. Available from: https://doi.org/10.1007/s10266-019-00463-1
37. Väyrynen VOE, Tanner J, Vallittu PK. The

anisotropicity of the flexural properties of an occlusal device material processed by stereolithography. J Prosthet Dent [Internet]. 2016;116(5):811–7. Available from: http://dx.doi.org/10.1016/j.prosdent.2016.03.018

38. Kadokawa A, Suzuki S, Tanaka T. Wear evaluation of porcelain opposing gold, composite resin, and enamel. J Prosthet Dent. 2006;96(4):258-65.
39. Hammouda IM. Effect of light-curing method on wear and hardness of composite resin. J Mech Behav Biomed Mater. 2010;3(2):216-22.