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PRESSURE THERMOFORMED VS. MILLED OCCLUSAL DEVICE WEAR CHARACTERISTICS AGAINST ZIRCONIA

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ABSTRACT

Milled versus pressure thermoformed occlusal device wear characteristics against zirconia

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Introduction: Occlusal devices are often provided to prevent wear of dentition and damage to restorative materials. In a dental landscape of increasing material choices and fabrication methods, there is a wide array of options from which to choose. If clinicians are less prescriptive and leave these decisions to the dental laboratory, then ease of workflow may influence which device is fabricated. Two commonly fabricated occlusal devices at a local dental laboratory include milled polymethylmethacrylate (PMMA) and a pressure-molded thermoplastic polyurethane (TPU)/polyethylenterephthalat-glycol copolyester (PET-G). **Objective**: The purpose of this *in vitro* study was to determine if there were any differences in the amount of wear between PMMA and TPU/PET-G materials in a simulated chewing of one year. **Methods**: Four samples of PMMA and four samples of TPU/PET-G were subjected to abrasion by cusp-shaped 5Y-TZP zirconia antagonists in a dual-axis chewing simulator (Chewing Simulator-4) for 240,000 loading cycles. Wear was analyzed by measuring vertical material loss. A mean and standard

deviation were determined per group. Data were analyzed using the Mann-Whitney U test and substantiated by Student's t-test. **Results**: Mean material loss of PMMA was 0.228 ± 0.028 mm, while mean material loss of TPU/PET-G was 0.56 5± 0.080 mm. Statistical analysis using the Mann-Whitney U test resulted in a p-value of 0.028, suggesting that there are differences in the mean amount of wear between the two materials. **Conclusions**: Apparent wear reveals that milled PMMA outperforms TPU/PET-G by approximately twofold in a one-year *in vitro* chewing simulation. In this respect, a milled PMMA occlusal guard may be considered superior to pressure molded TPU/PET-G against one year simulated usage. Further studies should be conducted using additional restorative and occlusal device material options.

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LIST OF ABBREVIATONS

5Y-TZP	5 mol% yttria-stabilized tetragonal zirconia polycrystalline
GPT	Glossary of Prosthodontic Terms
PET-G	Polyethylenterephthalat-Glycol Copolyester
PMMA	Polymethylmethacrylate
TPU	Thermoplastic polyurethane

CHAPTER 1: Introduction

Occlusal devices are known by several names in the literature, including occlusal splint, stabilization splint, mouth guard, occlusal appliance, orthotic device, bite guard, bite plate, stent, and night guard, among others. While they are still often prescribed as potential therapy for sleep bruxism, there is lack of convincing causal evidence for this[1-3]. Consensus does exist, however, on the clinical benefits of occlusal devices in protecting existing dentition and restorations against attrition that may occur secondary to sleep bruxism[1-6].

The Ninth Edition of the Glossary of Prosthodontic Terms (GPT-9) defines bruxism as the parafunctional grinding of teeth, or an oral habit consisting of involuntary rhythmic or spasmodic nonfunctional gnashing, grinding, or clenching of teeth, in other than chewing movements of the mandible, which may lead to occlusal trauma[7]. Bruxism is a common disorder, with a prevalence of up to 31%[8]. Possible tooth-related consequences to bruxism include tooth wear (especially attrition); fracture or failure of teeth, restorations or implants; and sensitivity or pain of teeth, muscles or joints.[9] By focusing on wear without differentiation between sleep and awake states[10], occlusal devices may be considered for use in prevention of damage to natural dentition and restorations secondary to bruxism. Prosthodontic treatment often requires a combination of several direct and indirect restorations to restore form and function. An occlusal device is provided at the end of treatment to preserve restorations, honoring the time and effort contributed by both the patient and provider. Among the definitions listed in the GPT-9, use of an occlusal device includes prevention of wear of the dentition or damage to brittle restorative material[7].

Practitioners must strive to deliver restorations that exhibit similar wear to enamel or opposing restorations. This is done in an effort to reduce differential wear and maintain long-

term stable contacts[5]. The same goals should be made of an occlusal device when employed for the protection of natural teeth and restorations. There is a myriad of materials and designs to meet these goals. The ideal protective occlusal device has been described as a laboratory-processed acrylic resin that covers the occlusal surfaces of all the teeth in one arch[5]. Acrylic resin has been widely used as denture teeth in part due to convenient handling properties and better fracture toughness[11]. However, newer materials on the market have challenged the use of acrylic resins for occlusal devices due to the ease of fabrication and seemingly adequate material properties. Some of these materials include thermoplastic polymers such as polyethylenterephthalat-glycol copolyester (PET-G). In addition to laboratory-processed acrylic resin, computer-aided manufacturing has brought newer materials to market. Conventionally fabricated occlusal devices, including those made by pressure/vacuum thermo-molding, chemical or heat polymerization technique, have been joined by subtractive and additive methods. These include milling and grinding for subtractive manufacturing, or stereolithography, selective laser sintering, photo-curing print, and fused deposition modeling for additive manufacturing[12]. Milling can reduce fabrication flaws by reducing porosities and inhomogeneous consistencies, perhaps more than current additive techniques[13]. The multitude of methods for fabrication of an occlusal guard and the corresponding materials warrants evaluation. While each method should display wear behavior comparable to conventionally made occlusal devices, laboratory capability and workflow decisions may outpace provider knowledge.

The wear properties of current occlusal device materials may differ based on fabrication method. This may be of interest to both the patient and provider, as wear rates may affect expectations for the maintenance of restorations in cases of bruxism, particularly with full mouth rehabilitations. The literature is scarce when comparing the efficacy of occlusal guards based on

fabrication methods, although it has been suggested that some 3D-printed resins may have lower flexural strength and hardness values and higher water sorption and solubility[14]. Some options that clinicians may consider are conventionally fabricated occlusal devices and those made by subtractive manufacturing. If clinicians are not as prescriptive and leave this decision to the laboratory, however, then ease of workflow may predominate as to which device results. The purpose of this study was to compare the wear properties of occlusal devices fabricated by conventional and subtractive techniques against a common restorative material. The null hypothesis postulated that there were no wear differences between the occlusal guard materials regardless of fabrication technique.

CHAPTER 2: Materials and Methods

Cusp-shaped antagonist abraders were designed using CAD/CAM software (exocad, exocad GmbH, Darmstadt, Germany). The artificial cusp was designed with a slight conical shape and a 2-mm-diameter round tip, which was used as a template to produce standard antagonists with the restorative material listed in *Table 1*.[15] Zirconia (IPS e.max ZirCAD Prime, Ivoclar Vivadent, Liechtenstein) antagonists were milled using a 5-axis mill (CORiTEC 150i, imes-icore, Eiterfeld, Germany). Zirconia antagonists were sintered, polished, and placed in the antagonist holder of the chewing simulator (Chewing Simulator-4, SD Mechatronik, Westerham, Germany), translucent portions (5Y-TZP) contacting the samples. Cusps were fixed using a custom-made specimen holder. Each sample was loaded against an antagonist cusp at 1.6 Hz for a total of 240,000 chewing cycles in three phases: 200N vertical force, 0.7 mm horizontal sliding, and separation. Parameters for the chewing simulator are listed in *Table 2*.[16]

Two commonly used occlusal device materials were chosen to represent both conventionally fabricated (pressure thermoformed) and subtractive (milled) manufacturing methods. *Table 3* lists these materials and their compositions. Samples (n=4) of each material (8 total samples) were fabricated. Milled polymethylmethacrylate samples (PREMIOtemp Mono, primotec, Bad Homburg, Germany) were fabricated using a 5-axis milling unit (CORiTEC 150i, imes-icore, Eiterfeld, Germany). Conventional pressure molded samples (Durasoft, Scheu-Dental, Iselohn, Germany) were fabricated using a positive pressure thermoforming machine (Biostar, Great Lakes Dental, Buffalo, New York). Samples were mounted in the sample holder of a chewing simulator (Chewing Simulator-4, SD Mechatronik, Westerham, Germany). Sample materials were subjected to antagonist abraders.

The maximum vertical wear of the sample materials was quantified using a model scanner (Freedom HD, DOF, Seoul, South Korea) and 3D modeling software (Materialise 3-matic Medical version 16.0, 3DZ Group, Malta). A three-dimensional mesh was obtained from the model scanner and subsequently imported into the 3D modeling software. Indentation depth was determined by measuring the radii of two circles (*Figure 1*). The first circle, C_1, was fit to the edge formed by the intersection of the indentation and the surface of the sample. The second, C_2, was fit to the apex of the indentation and two points along C_1 perpendicular to the surface of the sample. The following methodology was used to determine the depth of the indentation based on the relationship between the two circles:

Using a conventional coordinate system with the origin at the center of C_2, the Y coordinate was determined given its associated X location and the radius of the circle by rearranging Equation (1) to Equation (2):

Equation of C_2:

$$(X_2-H_2)^2 + (Y_2-K_2)^2 = R_2^2 \qquad (1)$$

Assuming the center of the circle is at (0,0) and solving for Y_2

$$Y_2 = \mathrm{sqrt}(R_2^2 - X_2^2) \qquad (2)$$

Since C_1 and C_2 intersect where C_1 passes through the surface of the sample, use equation (2) can be used to calculate the Y location of the sample surface. Substituting equation (2) into equation (3) allows for the determination of indentation depth using the radius of both circles.

$$\Delta H = R_2 - Y_2 \qquad (3)$$

$$\Delta H = R_2 - \mathrm{sqrt}(R_2^2 - R_1^2) \qquad (4)$$

A Mann-Whitney U test was conducted to compare the mean vertical loss between the two occlusal guard samples.

CHAPTER 3: Results

Vertical material loss is listed in *Table 4*. Mean values are listed in *Table 5*. The graph in *Figure* 2 represents the average vertical loss measured from four milled PMMA samples, shown in the bar chart on the left, and four pressure thermoformed copolyester samples, shown in the bar on the right, using 3D modeling software. Y-axis presents mean vertical loss after one year chewing simulation in millimeters. The average vertical loss of milled PMMA samples was 0.228. Standard deviation was 0.028. The average vertical loss of pressure thermoformed samples was 0.565 and standard deviation was 0.08.

CHAPTER 4: Discussion

Occlusal devices are historically thought of as treatment for bruxism, though that has been debated in the literature. A 2008 Cochrane Review by Macedo, et al, evaluated occlusal devices as interventions for treating sleep bruxism (tooth grinding). In the review, the authors cite inconclusive results on bruxism management, but suggest that there may be some benefit to occlusal guards with regard to tooth wear and restoration failure.[1] Given the inconclusive results on bruxism management within available literature, the 'triple-P' approach published by Lobbezoo, *et. al.* in 2008 continues to be recommended; that is, a combination of *occlusal devices* (ie, 'plates'), counseling/behavioral strategies (ie, 'pep talk'), and centrally-acting drugs (ie, 'pills')[17]. Carefully designed and implemented occlusal devices, then, have a role in protecting tooth structure and restorations from excessive wear and potential fracture due to bruxism. Thus, through robust literature evaluating the inconclusive effects of occlusal devices as treatment for bruxism, the existing literature has acknowledged that occlusal devices may have benefits in protecting existing dentition and preventing damage to dental restorations.

The results of this study suggest that when comparing apparent wear, milled PMMA outperformed the copolyester by almost twofold in a one-year in vitro chewing simulation. The clinical significance is that milled PMMA occlusal guards may last longer than what we see as a common alternative. This could translate to getting longer lifespans out of our restorations if a milled PMMA occlusal guard is chosen over the thermoformed alternative. The null hypothesis, which postulated that there are no wear differences between the occlusal guard materials regardless of fabrication technique, was rejected. Grymak, *et. al.* in 2021 published a systemic review evaluating wear behavior of occlusal splint materials manufactured by various methods.[18]

They reported a consensus that vacuum-formed materials displayed the highest wear when compared to other manufacturing methods. This is consistent with the results of this study.

There are several limitations to this study, not least of which are the vast numbers of antagonist and occlusal guard materials available, as well as multiple fabrication techniques for many of them. This study evaluated one antagonist material, a 5Y-TZP zirconia, and two common occlusal guard materials - milled PMMA and TPU/PET-G copolyester. Further studies should be used to evaluate other common restorative materials, including 3Y-TZP and 4Y-TZP zirconia, lithium disilicate, gold alloys, resin-based composites, and enamel substitutes, to name few.

This *in vitro* two-body wear was performed using a common chewing simulator.[15, 16, 19-22] Chewing simulators function in a finite path, which may fail to account for individual parafunction. Another limitation to this study is that the method by which wear was produced in the simulation may not replicate a patient's particular chewing or bruxism habits. Likewise, parameters chosen for the chewing simulation are not uniform across studies; rather they are an amalgamation of various studies. Examples of these inconsistencies can be seen in both numbers of cycles and testing force. While some studies recommend 240,000 chewing cycles – the number used in this study - to simulate one year of use[22], other studies recommend 250,000.[18] Neither of these values, however, may be analogous to the amount of bruxing sensations experienced in one year. Wear from tooth-to-tooth contact - a result of clenching, bruxism, or parafunction – may occur closer to 71,000 cycles.[18] Finally, when considering bite force, normal function is reported in the range of 10 to 120N[22]. Maximum bite force has been reported as reaching approximately 700N.[23] Furthermore, it has been suggested that a single point contact applies a force of 49 to 50N.[18] Thus, the chosen parameter of 200N for this study perhaps

represents moderately-heavy bruxism, a sort of worst-case scenario for an occlusal device that can lead to early replacement. Variations such as those described underscore the assertion that there should be standardization with *in vitro* wear testing.[18]

A final limitation is that this *in vitro* study compared vertical loss, while other studies in the literature have advocated for volumetric loss. It is the author's opinion that vertical loss is of equal clinical significance, as visible loss – or show-through of the occlusal device – may prompt the patient or provider for replacement.

CHAPTER 5: Conclusions

Apparent wear reveals that milled PMMA outperforms TPU/PET-G by approximately twofold in a one-year *in vitro* chewing simulation. In this respect, a milled PMMA occlusal guard may be considered superior to pressure molded TPU/PET-G against one year simulated usage. Further studies should be conducted using additional restorative and occlusal device material options. Clinicians may need to be deliberate on types of materials and, perhaps, manufacturing methods when requesting prostheses from a dental laboratory.

Table 1. Antagonist material.

Material	Product	Manufacturer
Zirconia (5Y-TZP)	IPS e.max ZirCAD Prime	Ivoclar Vivadent, Liechtenstein

Table 2. Chewing simulator parameters.

Parameter	Data
Number of cycles	240,000
Force	200 N
Height	3 mm
Lateral movement	~0.7 mm
Descendent speed	60 mm/s
Lifting speed	60 mm/s
Feed speed	40 mm/s
Return speed	50 mm/s
Frequency	1.6 Hz

Table 3. Occlusal device material samples.

No.	Material	Manufacturer	Method	Composition
1	PREMIOtemp Mono	Bad Homburg, Germany	Milled	Polymethylmethacrylate (PMMA)
2	Durasoft	Scheu-Dental, GmbH, Iselohn, Germany	Pressure thermoformed	Thermoplastic polyurethane (TPU) / Polyethylenterephthalat-Glycol Copolyester (PET-G)

Table 4. Vertical loss measurements following chewing simulation.

Sample ID	Radius Circle 1 (C_1)	Radius Circle 2 (C_2)	Calculated Depth (mm)
PMMA 1	2.22	0.92	0.200
PMMA 2	1.73	0.91	0.259
PMMA 3	1.86	0.85	0.206
PMMA 4	1.16	0.71	0.243
TPU/PET-G 1	1.53	1.22	0.607
TPU/PET-G 2	1.73	1.34	0.636
TPU/PET-G 3	1.97	1.27	0.464
TPU/PET-G 4	1.62	1.22	0.554

Table 5. Mean vertical loss comparisons following chewing simulation.

Material	Mean Vertical Loss (mm)	Standard Deviation	Standard Error	95% Confidence Interval	
PMMA	0.228	0.028	0.014	0.183	0.270
TPU/PET-G	0.565	0.080	0.040	0.439	0.690
p-Value	0.029				

Figure 1. Digital rendering of scanned indentation following chewing simulation, marked with radii of two circles for determination of depth.

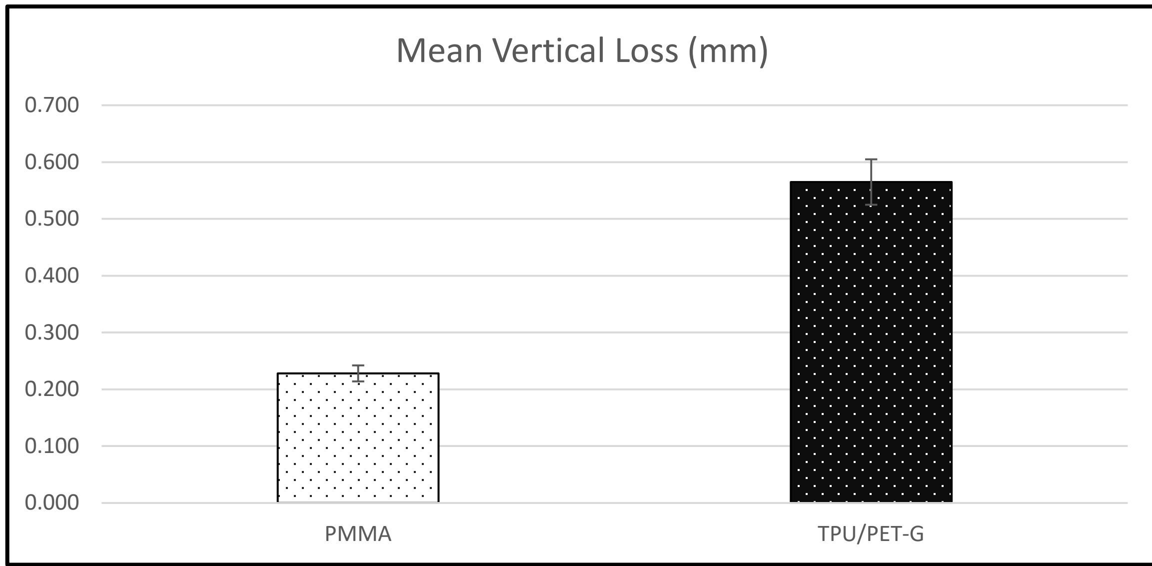

Figure 2. Mean vertical loss (mm) with standard error bars for PMMA and TPU/PET-G groups.

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