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The effect of thermo-mechanical fatigue on the retentive force and dimensional changes in polyetheretherketone clasps with different thickness and undercut

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PURPOSE. Esthetic expectations have increased the use of polyetheretherketone (PEEK) clasps as alternatives to Cr-Co in removable partial dentures (RPDs). The objective of this study was to evaluate the retentive force and dimensional change of clasps with different thickness and undercut made from PEEK by the thermo-mechanical fatigue. **MATERIALS AND METHODS.** PEEK clasps (N = 48) with thicknesses of 1 or 1.50 mm and 48 premolar monolithic zirconia crowns with undercuts of 0.25 mm or 0.50 mm were fabricated. Samples are divided into four groups (C1-C4) and were subjected to 7200 thermal aging cycles (at 5 - 55°C). The changes in the retentive force and dimensions of the clasps were measured by micro-stress testing and micro-CT devices from five measurement points (M1 - M5). One-way ANOVA, paired t-test, two-way repeated ANOVA, and post-hoc tests were used to analyze the data ($P < .05$). **RESULTS.** The retentive forces of C1, C2, C3, and C4 groups in initial and final test were found to be 4.389-3.388 N, 4.67 - 3.396 N, 5.161 - 4.096 N, 5.459 - 4.141 N, respectively. The effects of retentive force of all PEEK clasps groups were significant decreased. Thermo-mechanical cycles caused significant dimensional changes at points with M2, M4, and M5, and abraded the clasp corners and increased the distance between the ends of the clasp, resulting in reduced retentive forces ($P^* = .016$, $P^* = .042$, $P < .001$, respectively). **CONCLUSION.** Thermo-mechanical aging decreases the retentive forces in PEEK clasps. Increasing the thickness and undercut amount of clasps decreases the amount of dimensional change. The values measured after aging are within the clinically acceptable limits. [J Adv Prosthodont 2021;13:304-15]

KEYWORDS
Polyetheretherketone; Removable partial denture; Clasp retainer; Nonmetal clasp; Fatigue

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INTRODUCTION

Despite the developments in implant dentistry, some patients with missing teeth prefer removable partial dentures (RPDs) due to health, anatomical, psychological, and financial problems.[1]

One of the biggest problems of removable partial dentures is that the clasps are visible. Materials used for RPDs are limited. Cobalt-chrome (CoCr) alloys clasps have long been in use.[2] Although CoCr clasps are retentive, they are unaesthetic, and they may cause allergic problem and periodontal issues.[3] Due to these disadvantages, the usage of new materials made of high-performance thermoplastic polymers such as PEEK for clasp material in RPDs[4-8] is needed.

In recent years, PEEK material has become popular in dentistry because of its superior properties. It is biocompatible, aesthetic, and resistant to mechanical, thermal stresses, bacterial retention and low level of liquid absorbency.[5]

It also has low weight, which is favorable especially in maxillary removable partial prosthesis.[4] Because of its high flexibility, PEEK clasps cause less stress on abutment teeth and may be more resistant to deformation or fracture than Co-Cr alloys.[9,10]

PEEK material is widely used in fixed partial prosthesis, RPDs, implant supported fixed prosthesis, hybrid prosthesis, and telescope crowns.[11] The clasps made of PEEK are presented to patients as an alternative because of its elasticity and resistance to the traumatic forces.[3,12-14]

Clasp retentive force is directly proportional to elastic modulus, thickness, width, the degree of undercut, and is inversely proportional to the length of the clasp arm.[15,16] The material from which the clasps are made also affects the retentive force. Tannous *et al*. reported cobalt-chrome (CoCr) clasps to have higher retentive force values than thermoplastic resin clasps, but considered them to be clinically acceptable.[13]

Fatigue resistance of dental materials is a significant factor for clinical stability. Clasp assemblies made of different materials engaging different undercuts have been announced to differ according to fatigue resistance.[17,18] In the course of time, clasp fatigue may cause permanent deformation of the clasps and loss of retentive force.[18,19]

Felicitas *et al*. reported that the retentive force of clasps made of PEEK in comparison with those made of cobalt-chrome-molybdenum (CoCrMo) showed lower values after storage in water and artificial aging with thermocycling.[4]

Clasps are the retaining elements of removable partial dentures that attach to abutment teeth. They ensure that the denture remains stable in the mouth during speech and chewing. In the literature, there are not many studies on the retentive force and dimensional changes of clasps made of PEEK material, which is used as a clasp element in removable partial dentures, after thermo-mechanical fatigue. The aim of this study was to examine the retentive force and deformations of PEEK clasps with different undercut (0.25 and 0.50 mm) and thickness (1 and 1.5 mm) after thermo-mechanical fatigue. The null hypothesis was that thermo-mechanical fatigue would not affect the retentive force and dimensional change of PEEK clasps with different undercut and thickness.

MATERIALS AND METHODS

An artificial maxillary right second premolar tooth (Klas Dental, Ankara, Turkey) was prepared for a surveyed monolithic zirconium crown (MZC).[20] The abutment teeth (N = 48) were reproduced from Polymethylmethacrylate (PMMA) discs (DuoCad, FSM Dental, Ankara, Turkey) with CAD-CAM machine. The crown was designed to be a spoon-shaped tab housing 2.5 $\times$ 2.5 $\times$ 2 mm in size and to contain the medial triangular fossa and mesial margin (DWOS-crown&bridge, Dental Wings, Montreal, QC, Canada).[21-23] By preparing a guide plane covering 2/3 of the crown height in two different undercuts (0.25 mm and 0.50 mm),[13,24] in the distobuccal gingival 1/3, MZC crowns (N = 48) were produced with semi-sintered zirconium and sintered according to the manufacturer's recommendations. The dimensions of the produced crowns and their fitting with the abutment teeth were checked. Samples with appropriate undercut and thickness were included to study. Incompatible samples were excluded and reproduced.

The crowns were cemented with dual-cure self-adhesive resin cement (Breeze™ Self-Adhesive Resin Cement, Pentron, Wallingford, England), following the instructions of the manufacturers.[25] A master model was planned to place an Akers clasp on maxillary right second premolar tooth in a digital medium according to the path of insertion of the crown on the 3D digital image the CAD system (DWOS-Partial frameworks, Dental Wings Inc., Montreal, Canada) (Fig. 1). It was calculated that a sample size of 12 in each group should be included in this study, according to 0.35 loss of the retentive force among C1-C4 groups before and after thermo-mechanical fatigue, and error level of α = .05 and β = .02.

Clasps were produced in four different groups: C1: 1 mm thickness and 0.25 mm undercut (n = 12), C2: 1 mm thickness and 0.50 mm undercut (n = 12), C3: 1.5 mm thickness and 0.25 mm undercut (n = 12), and C4: 1.5 mm thickness and 0.50 mm undercut (n = 12) (Fig. 2), with disc-containing pure silk (Juvora™, Juvora Ltd., Lancashire, UK) in the CAM of the clasps. They were not subjected to additional polishing. A digital micrometer was used to verify the clasp dimensions after the finishing and polishing procedures (Mitutoyo, model 500-144B, Tokyo, Japan).

The retentive force and dimensional change of PEEK clasps have been evaluated according to two different thickness (1 and 1.5 mm) and undercut (0.25 and 0.50 mm) values over five-years thermo-mechanical fatigue (T-MF) on MZC examined in a repetitive insertion removable test simulating clinical use. The change of retentive force and dimension of the clasps were performed with a micro tensile and a μ-CT device. The devices and materials used in the study are presented in Table 1 and Table 2.

Test stages have been carried out in the following order:

Initial-test (INTL): μ-CT images of clasps, SEM and determination of retentive force,

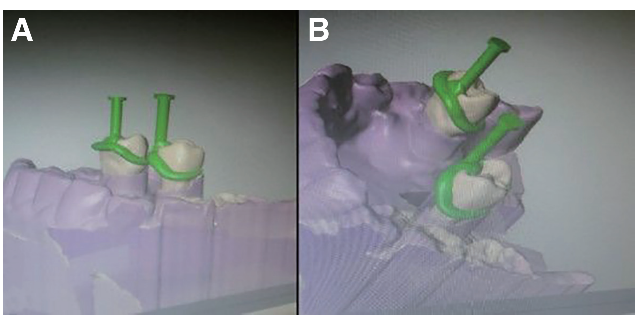

Fig. 1. The 3D image of the clasps designed in1 mm (A) and 1.5 mm thickness (B) in DWOS-partial frameworks software.

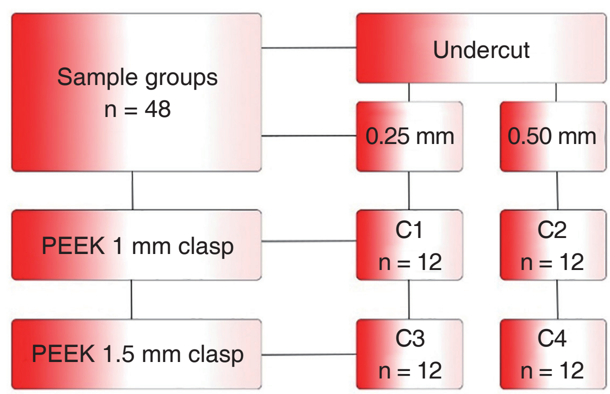

Fig. 2. The scheme of sample groups.

Table 1. The devices used in the study

Device	Model	Brand	Producer
CAD-CAM Milling Device (PMMA and PEEK)	D30	Yenamak	Yenamak, Istanbul, Turkey
CAD-CAM Milling Device (ZrO_2)	D15	Yenadent	Yenadent, Istanbul, Turkey
Microtensile Test (MTT) Device	MTD-500	SD Mechatronik	SD Mechatronik GmbH, Feldkirchen, Germany
Chewing Simulator (CS)	CS-8	SD Mechatronik	SD Mechatronik GmbH, Feldkirchen, Germany
Thermal Cycle Device	FT-400 cooler	Julabo	Julabo GmbH, Seelbach, Germany
	ED heat exchanger	Julabo	Julabo GmbH, Seelbach, Germany
Microcomputerized Tomography Device (Micro-CT)	SkyScan 1272	Bruker	Bruker Corp., Kontich, Belgium
Scanning Electron Microscope (SEM)	EVO® LS10	ZEISS	Carl Zeiss Microscopy GmbH, Jena, Germany
Digital micrometer	500-144B	Mitutoyo	Tokyo, Japan

Table 2. Materials used in the study

	Material	Brand	Product, Producer	Batch number
Abutment crowns	ZrO_2 CAD-CAM Disc	Upcera Zr-White	Liaoning Upcera Co., Ltd., Liaoning, China	L425012345-2
	ZrO_2 (glaze) Liquid	Vita Akzent® plus	VITA Zahnfabrik, Bad Säckingen, Germany	54210
Clasps	PEEK CAD-CAM Disc	Juvora™	Juvora Ltd., Lancashire, UK	J000102

Final-test (FNL): After completion of T-MF determined final retentive forces, μ-CT, SEM imaging of the clasps, respectively.

To determine the dimensional changes, each clasp was fixed in the same vertical distance obtained by the μ-CT images of INTL and FNL. The standard parameters applied to the INTL and FNL images of each clasp were superimposed by using reference points.[24,25] INTL and FNL-test μ-CT images were as follows: pixel dimension 8 ns; resolution 3K; values of x-ray energy sources 50 kV and 200 mA (without filter); irradiation duration 230 ms. The image sections of each clasp were taken throughout 1800 with intervals of 2°. They were first uploaded to the protocol file determined in the NRecon (SkyScan 1272, Skyscan, Aartselaar, Belgium) program and then 90 images were reconstructed and transferred to DataViewer (DataViewer software, v 1.5.2, SkyScan, Aartselaar, Belgium) program (Fig. 3, Fig. 4).

The quantification of clasp deformation was conducted by drawing a tangent line in the digital medium to the ends of quantification points determined in five different areas. Measurements were performed by one researcher five times in the digital medium and the averages of the obtained data were taken.

M1 and M2: The distance from the top point of the clasp to the farthest point of the clasp and the farthest point of the reciprocal arm, respectively.

M3: The distance between the farthest points of the retentive and reciprocal arms

M4 and M5: The clasp thickness in the area where the reciprocal arm meets the undercut and the arm of retentive clasp meets the undercut, respectively (Fig. 5).

To study the changes that might potentially develop on the surface of the crown and the clasp couple, one crown-clasp couple from each group was examined with INTL and FNL T-MF effect under a scanning electron microscope (Carl Zeiss EVO LS 10, Carl Zeiss NTS, Oberkochen, Germany)(Fig. 6, Fig. 7).

To measure the initial and the final retentive forces of the clasps of each group, the crown-clasp specimens were installed in a micro stress device and each measurement was repeated five times. Data were recorded. The average of recorded values was calculated.

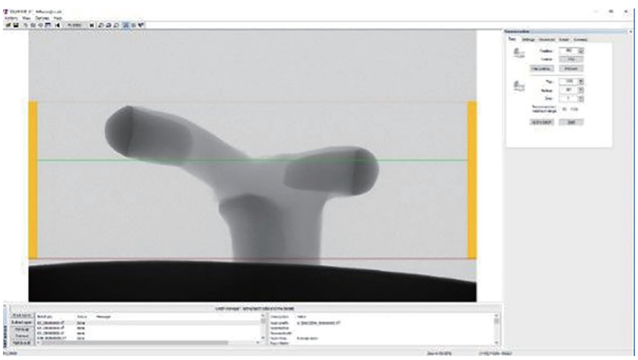

Fig. 3. PEEK clasp imaged in 3D Micro-CT.

Fig. 4. Superimposed clasp images in the Data Viewer program.

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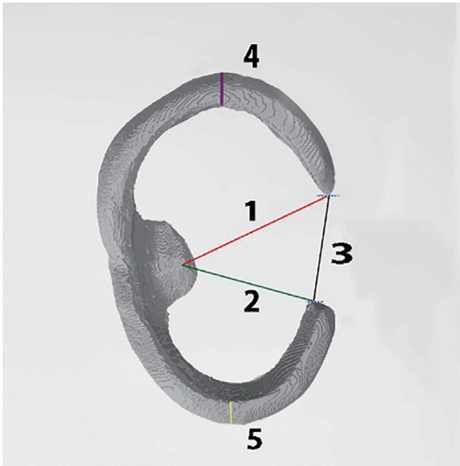

Fig. 5. Reference points digitally determined in five different areas on the clasp (M1-5).

The sample couples of clasp-crown were attached to the chewing simulator. Mechanical fatigue, at 7200 cycles[18,24,25] under a 3 kg load,[26] with a speed of 10 mm/s[24] and a frequency of 0.5 Hz,[24,27] which represented a five-year use was applied. The samples were kept for ten seconds in distilled water with a temperature of 5 - 55°C, which changed every 60 sec, while the mechanical cycle was repeated 7200 times in a chewing simulator, owing to the difference of frequency between the thermal and mechanical cycles in the device itself, thermal fatigue was completed in a TC device. Therefore, the samples were taken to the TC device in distilled water, the temperature of which changed between 5 - 55°C every 60 seconds.[28]

Two-way repeated measures analysis of variance was used to compare the groups (clasp groups (groups C1: 1 mm thickness and 0.25 mm undercut (n = 12), C2: 1 mm thickness and 0.50 mm undercut (n = 12), C3: 1.5 mm thickness and 0.25 mm undercut (n = 12), C4: 1.5 mm thickness and 0.50 mm undercut (n = 12) (C1-C4)) with dimensional deformation measurement parameters (time; M1-5-initial and final) and retentive force (time; initial and final) measurements). The one-way analysis of variance (ANOVA) was used to compare the differences among the clasp groups (C1-C4) measurements in each of dimensional deformation measurement parameters (M1-5-initial and final) and retentive force (initial and final) measurements. The Tukey method was used as the multiple comparison test in cases where the one-way ANOVA result was significant. The comparison in each of clasp groups (C1-C4) of dimensional deformation measurement parameters (M1-5-initial and final) and retentive force (initial and final) values was made us-

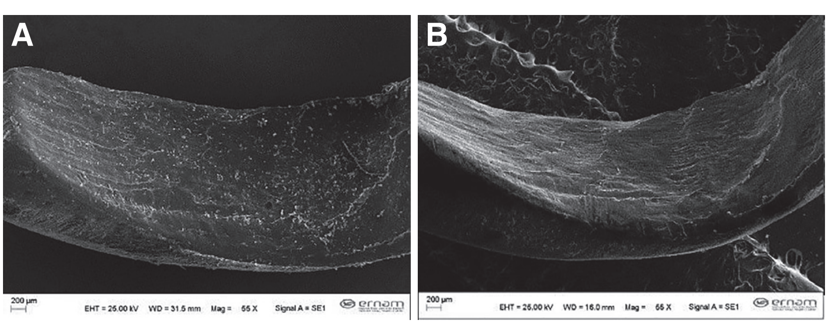

Fig. 6. The initial (A) and final thermo-mechanical fatigue (B) SEM images (55×) of a clasp in the C2 (0.50/1 mm) group.

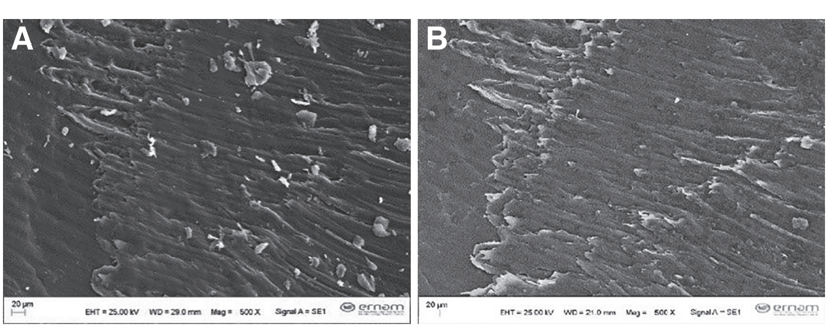

Fig. 7. The initial (A) and final thermo-mechanical fatigue (B) SEM images (500×) of a clasp in the C2 (0.50/1 mm) group.

ing a paired t-test. Data analysis was performed in TURCOSA Cloud-based statistics software (Turcosa Analytics Ltd. Co., Kayseri, Turkey).[29] Significance level was accepted as $P < .05$.

RESULTS

In all clasp groups, difference between the retention INTL and FNL measurements showed a statistically significant decrease ($P < .001$). While the difference between the groups in the INTL and FNL measurement of the retention variable was not found statistically significant according to the two-way repeated measurement analysis of variance ($P = .082$), a significant difference was found between the main effects and time of RET (retentive force) ($P < .001$, Table 3).

According to paired t-test, the effect of T-MF on the retentive forces in all clasp groups showed a statistically significant difference between the RET-INTL and -FNL measurements ($P^* < .001$). The difference in the groups in RET-INTL and -FNL measurement was found statistically significant in the one-way analysis of variance ($P^\# < .001$). According to the multiple comparison test (Tukey), C1 and C2 groups were found to be significantly different from C3 and C4 groups for both ret-initial and ret-final ($P < .05$, Table 3).

The changes in M1-5 measurements used to evaluate the effect of the fatigue on the dimension in four different groups of clasps have been presented in Table 4.

In all clasp groups, according to the two-way repeated measurement analysis of variance, while the interaction of the groups between the M1 INTL and M1 FNL measurement of the fatigue variable did not show statistically significant difference ($P = .423$), the main effects and time of fatigue was found significantly different ($P < .001$, Table 4).

According to paired t-test, the effect of fatigue on the dimension in all clasp groups showed a statistically significant difference between the M1 INTL and M1 FNL measurements (C1; $P^* = .002$, C2; $P^* < .001$, C3; $P^* < .001$ and C4; $P^* = .003$). The difference in the groups M1 INTL and M1 FNL measurement was found statistically significant in one-way analysis of variance (respectively $P^\# < .002$ and $P^\# < .001$) (Table 4). According to the multiple comparison test (Tukey), C1 and C2 groups were found to be significantly different from C3 for M1 INTL ($P < .05$). C1 and C2 groups were found to be significantly different from C3 for M1 INTL ($P < .05$). C2 group was found to be statistically significant than C3 and C4 groups for M1 INTL ($P < .05$). C1 and C2 groups were found to be significantly different from C3 for M1 FNL ($P < .05$). C2 group was found to be significantly different from C3 and C4 for M1 FNL ($P < .05$, Table 4).

In all clasp groups according to the two-way repeated measurement analysis of variance, while the interaction and time of the groups between the M2 INTL and M2 FNL measurement of the fatigue variable showed statistically significant difference (respectively $P = .016$ and $P < .001$), the main effects of fatigue did not show significant difference ($P = .934$, Table 4).

According to paired t-test, the effect of fatigue on the dimension in all clasp groups showed a statistically significant difference between the M2 INTL and M2 FNL measurements (C1; $P^* = .001$, C2; $P^* < .001$, C3; $P^* < .001$ and C4; $P^* = .018$). The difference in the groups M2 INTL and M2 FNL measurement was not found statistically significant in the one-way analysis of variance (respectively $P^\# < .945$ and $P^\# < .729$, Table 4).

In all clasp groups according to the two-way repeated measurement analysis of variance, while the interaction of the groups between the M3 INTL and M3 FNL measurement of the fatigue variable did not show statistically significant difference ($P = .394$), the main effects and time of fatigue showed a significant difference ($P < .001$, Table 4).

According to paired t-test, the effect of fatigue on the dimension in all clasp groups showed a statistically significant difference between the M3 INTL and M3 FNL measurements (C1; $P^* = .009$, C2; $P^* < .001$, C3; $P^* < .001$ and C4; $P^* = .005$). The difference in the groups M3 INTL and M3 FNL measurement was found statistically significant in the one-way analysis of variance (respectively $P^\# < .025$ and $P^\# < .001$). According to the multiple comparison test (Tukey), C1 and C2 groups were found to be significantly different from C3 group for M3 INTL ($P < .05$). C1 group were found to be significantly different from C3 and C4 groups for M3 FNL ($P < .05$, Table 4).

In all clasp groups according to the two-way repeated measurement analysis of variance, the interaction,

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Table 3. The change of RET (N) following thermo-mechanical fatigue for each clasp group

Values	Groups C1 $\bar{x} \pm sd$	C2 $\bar{x} \pm sd$	C3 $\bar{x} \pm sd$	C4 $\bar{x} \pm sd$	$P^{\#}$	P
RET-INITIAL	4.389 ± 0.399^{a}	4.670 ± 0.243^{a}	5.161 ± 0.368^{b}	5.459 ± 0.344^{b}	.082	Group < .001 Time < .001 Intr = .082
RET-FINAL	3.388 ± 0.323^{a}	3.396 ± 0.194^{a}	4.096 ± 0.490^{b}	4.141 ± 0.372^{b}		
P*	< .001	< .001	< .001	< .001		
RET DIFFERENCE	1.001 ± 0.249	1.303 ± 0.212	1.066 ± 0.527	1.318 ± 0.381		

C1-C4: Clasp groups, RET: Retentive force.
P*: paired t-test, $P^{\#}$: One-Way ANOVA, P: Two-way repeated ANOVA; Intr; (interaction), By Post Hoc test, different letters in alphabetical superscripts express the significance, and the same letters the insignificance, of the intergroup differences.

Table 4. The change in the values (M1-5) (μm) representing the dimensional deformation for each group of clasps

Dimensional Deformation Measurement	Clasp Groups C1 n = 12 $\bar{x} \pm sd$	C2 n = 12 $\bar{x} \pm sd$	C3 n = 12 $\bar{x} \pm sd$	C4 n = 12 $\bar{x} \pm sd$	$P^{\#}$	P
M1 INTL	6.437 ± 0.101^{ad}	6.470 ± 0.203^{ab}	6.225 ± 0.207^{c}	6.253 ± 0.199^{cd}	.002	Group = <.001 Time = < .001 Interaction = .423
M1 FNL	6.570 ± 0.154^{ac}	6.656 ± 0.228^{a}	6.353 ± 0.206^{b}	6.377 ± 0.197^{bc}	.001	
P*	.002	< .001	< .001	.003		
M1 difference	0.134 ± 0.112	0.187 ± 0.081	0.128 ± 0.105	0.123 ± 0.113		
M2 INTL	5.302 ± 0.528	5.250 ± 0.120	5.317 ± 0.138	5.263 ± 0.255	.945	Group = .934 Time = <.001 Interaction = .016
M2 FNL	5.432 ± 0.493	5.523 ± 0.194	5.477 ± 0.176	5.380 ± 0.319	.729	
P*	< .001	< .001	< .001	.018		
M2 difference	0.130 ± 0.094	0.273 ± 0.158	0.160 ± 0.091	0.117 ± 0.146		
M3 INTL	4.486 ± 0.200^{a}	4.318 ± 0.119^{a}	4.258 ± 0.122^{ab}	4.198 ± 0.382^{b}	.025	Group = <.001 Time = <.001 Interaction = .394
M3 FNL	4.689 ± 0.238^{a}	4.454 ± 0.116^{ab}	4.433 ± 0.102^{b}	4.310 ± 0.329^{b}	.001	
P*	.009	< .001	< .001	.005		
M3 difference	0.204 ± 0.224	0.136 ± 0.051	0.175 ± 0.119	0.112 ± 0.110		
M4 INTL	1.061 ± 0.021^{a}	1.050 ± 0.188^{a}	1.503 ± 0.384^{b}	1.519 ± 0.410^{b}	< .001	Group = <.001 Time = <.001 Interaction = .042
M4 FNL	1.018 ± 0.029^{a}	1.017 ± 0.012^{a}	1.420 ± 0.066^{b}	1.468 ± 0.053^{b}	< .001	
P*	< .001	< .001	< .001	.023		
M4 difference	-0.043 ± 0.024	-0.033 ± 0.012	-0.083 ± 0.047	-0.051 ± 0.067		
M5 INTL	1.077 ± 0.013^{a}	1.062 ± 0.020^{a}	1.513 ± 0.023^{b}	1.498 ± 0.042^{b}	< .001	Group = <.001 Time = <.001 Interaction = <.001
M5 FNL	1.038 ± 0.014^{a}	1.030 ± 0.014^{a}	1.338 ± 0.078^{b}	1.380 ± 0.146^{b}	< .001	
P*	< .001	< .001	< .001	.007		
M5 difference	-0.040 ± 0.014	-0.032 ± 0.017	-0.175 ± 0.076	-0.119 ± 0.125		

C1-C4: Clasp groups, M1-5: dimensional deformation measurement parameters, RET: Retentive force.
P*: paired t test, P: Two-way repeated ANOVA, $P^{\#}$: One-way ANOVA, By Post Hoc test: Tukey, different letters in the alphabetical symbols indicate that the difference between groups is significant and the same letters are not.

the main effects and time of the groups between the M4 INTL and M4 FNL measurement of the fatigue variable showed statistically significant difference (respectively $P = .042$), $P < .001$ and $P < .001$ (Table 4)).

According to paired t-test, the effect of fatigue on the dimension in all clasp groups showed a statistically significant difference between the M4 INTL and M4 FNL measurements (C1; $P^* < .001$, C2; $P^* < .001$, C3; $P^* < .001$ and C4; $P^* = .023$). The difference in the groups M4 INTL and M4 FNL measurement was found statistically significant in the one-way analysis of variance ($P^\# < .001$). According to the multiple comparison test (Tukey), C1 and C2 groups were found to be significantly different from C3 and C4 groups for M3 INTL and FNL ($P < .05$, Table 4).

In all clasp groups according to the two-way repeated measurement analysis of variance, the interaction, the main effects and time of the groups between the M5 INTL and M5 FNL measurement of the fatigue variable showed statistically significant difference (respectively $P < .001$, Table 4).

According to paired t-test, the effect of fatigue on the dimension in all clasp groups showed a statistically significant difference between the M5 INTL and M5 FNL measurements (C1; $P^* < .001$, C2; $P^* < .001$, C3; $P^* < .001$ and C4; $P^* = .007$). The difference in the groups M5 INTL and M5 FNL measurement was found statistically significant in the one-way analysis of variance ($P^\# < .001$)). According to the multiple comparison test (Tukey), C1 and C2 groups were found to be significantly different from C3 and C4 groups for M4 INTL and FNL ($P < .05$ (Table 4)).

After the fatigue, only inner surface of all the PEEK clasps showed partial erosion, and crystal phase. The greatest superficial changes were detected in C1 (0.25/1 mm) and C2 (0.50/1 mm) claps groups (Fig. 6, Fig. 7).

DISCUSSION

The aim of this study was to evaluate the retentive force and dimensional change of clasps with different thickness and undercut made from PEEK by the thermo-mechanical fatigue. The results revealed that there was a significant decrease in the retentive force of all the clasps and dimensional changes in five different areas following the thermo-mechanical fatigue (T-MF). Based on the results obtained, the null hypothesis that T-MF does not affect the change of retentive force and dimensional deformations was rejected. In the comparison of INTL and FNL retentive forces of PEEK clasps, all groups revealed significant decrease.

The retentive force is determined by tooth form and by clasp style. Tooth shape affects retention by determining the depth of undercut available for clasping. Flexibility is also important for clasp. The more flexible it is, the less retention it provides for removable partial denture. The flexibility of the clasp depends on its length, thickness and material from which it is made.[30] In this study, two different thicknesses (1.0 mm and 1.5 mm) and two different undercut (0.25 mm and 0.50 mm) have been selected to produce PEEK clasps.

Tannous *et al*. examined retentive forces and fatigue resistance of different thermoplastic resin clasps. They suggested the greatest retentive force for polyoxymethylene, polyetheretherketon, and polyetherketonketon clasps was found in the 1.5 mm thick clasps designed to engage the 0.50 mm undercut.[13] Based on the data, the effect of the thickness of PEEK clasp on the retentive force and dimensional change of T-MF are more effective than the undercut value. When we compare the same undercut and different thickness groups (C1, C3 and C2, C4), clasp thickness has more effect on retentive force. In the measurements in five different areas of each clasp, the effect of TMF on dimensional deformation was changed significantly compared to INTL-test values and the least affected values by this change were M1 and M3. There is no consensus on thermal cycle number of RPD in T-MF studies. However, there is no knowledge about the average life of PEEK framework or clasps. In our study, the retentive force of PEEK clasps has been assessed by simulating five years[17,22] of clinical use through a T-MF test applied with a chewing simulator and a TC device.

In the studies performed, the dynamic-fatigue tests applied to RPDs clasps made of different materials reflect clinical simulations lasting three to ten years.[13,31-34] In experimental studies, to reflect the clinical use of RPDs, the number of the dynamic fa-

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tigue cycle to be tested is determined by assuming the usage of the prostheses three to five times daily.[13,24,31-33] In our study, a total of 7200[17,24] insertion/removal cycles simulating five years of clinical use was applied.[24,35]

The main factor of the decrease in retentive forces of a clasp other than retention and stability is the stress accumulating on the material resulting from its stretching to the elastic limit while passing the undercut.[36,37] The forces on the clasp during masticatory function is more effective than insertion/removal. In the literature, the comparison of the effects of dynamic fatigue tests on the retentive force of the clasps covers only the retention loss during the insertion/removal.[13,22,27,31-33,38,39]

Dental literature reports that the necessary total retentive force for an RPDs is 20 N, and for each clasp of an RPDs containing 2 - 4 clasps, is between 5 and 10 N.[40] However, in a 10-year retrospective study, the mean clinically measured retentive force in RPDs with metal clasp is 2.3 N.[41] In our study, the highest retentive force obtained FNL thermo-mechanical fatigue was 5.5 N, and the lowest was 3.4 N.

A clasp should provide a retentive force of 5 N to function.[32,40] In studies assessing clasp retention, Co-Cr clasps with an undercut of 0.25 mm had a retentive force of 4.77 N. In a study, retentive force between 3.0 N and 7.5 N (0.3 kgf and 0.76 kgf) for Kennedy I RPDs[40] is enough, and a similar study has reported a retention between 3 N and 7.5 N. Within limitations, PEEK clasps for RDPs could provide adequate retention in clinical conditions.

There are many techniques to quantify the dimensional changes in materials, such as μ-computerized tomography (μ-CT).[20] This technique helps evaluate small objects without impairing the integrity of the original piece. It is a system of advanced technology with a mechanism of transforming a 3D object into 2D. It combines separate images and helps evaluate the desired areas comparatively by interposing the images.[42] On μ-CT images, dimensional changes in clasps revealed a decrease in the thickness of the clasp in M4 and M5, which is also corroborated with SEM images. The absence of any change in PEEK clasp and MZC surfaces suggests that PEEK clasps will not cause changes on surface of natural teeth either.

The reason to prefer CAD-CAM produced MZC in our study was to obtain dimensionally standardized crowns. For PEEK clasps, the elasticity is very important. In our study, the effects of the changes in the thickness and undercut values on the retentive force has been investigated. Data analysis revealed that the group with the greatest retentive force was group C4, which is close to C3 group.

Following the thermo-mechanical fatigue, statistically significant dimensional changes have been observed in all clasp groups in five measurement points (M1-5), and during the INTL and FNL measurements in four clasp groups (C1-4). The groups which were least affected by dimensional deformation were the C3 and C4 groups (1.5 mm in thickness), while the most affected ones were the C1 and C2 groups (1 mm in thickness). The least dimensional change in two ends of a clasp occurred in the C4 group.

Although clasps made of PEEK material, which have superior properties such as biocompatibility, aesthetics, flexibility, resistance to thermal and mechanical stresses, are used in removable partial dentures, this study does entail several limitations. Thermomechanical fatigue tests can simulate the insertion and removal cycles of a 5 - 10-year-old denture. However, it cannot fully meet the wearer's insertion and removal of the prosthesis and the oral environment. In addition, studies using different clasp designs may contribute for increasing the retention of the prosthesis and reducing the dimensional change. Since the current study is the first in the literature evaluating dimensional changes after fatigue cycling of PEEK clasps through imaging, we could not compare it with a similar study. Closest to our study, Marie *et al.*[43] compared the deformation and the retentive forces in ketone polymer clasps. In the study, the retentive force has been measured following the dynamic fatigue at 37°C in the device testing retentive force without removing from the setup, and dimensional deformation measurements have been done in three dimensions employing software using iterative punctum proximal algorithm. In our study, the dimensional changes on the clasp end on the digital images obtained with a laser scanner have been examined and assessed. Two different images of the same clasp INTL and FNL fatigue have been superimposed employing the reference points determined on the clasp, and the distances between the reference points have been measured. The results of this study presented that increasing the thickness and undercut amount of the PEEK clasps decreased the amount of dimensional change even after thermo-mechanical fatigue and their retentive forces were within clinically acceptable limits. Also, PEEK clasps, due to their slightly grayish white color, have a more aesthetic appearance more acceptable than the color of metal clasps. Thanks to these advantages, they can be used in clinical applications. Since the oral environment could not be fully simulated in the laboratory, the results need to be supported by clinical studies.

CONCLUSION

Within the limitations of this study, it was found that thermo-mechanical fatigue has effectively decreased the retentive force of PEEK clasps. The values measured after aging were within clinically acceptable limits. Increasing the thickness and undercut amount of the clasps decreased the amount of dimensional change. In terms of the retentive force and dimensional changes, clasp thickness has been found more effective than undercut. The retentive force of the C3 and C4 claps groups is within clinically acceptable limits. The C4 clasp group is the one clinically most retentive and dimensionally least deformed. M1-3 points of the quantification points in the C4 clasp group have been affected by thermo-mechanical fatigue less than the other points indicating dimensional changes (M2-4-5). In all clasp groups, M2 point has not affected the dimensional change.

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