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Influence of aging of PEEK attachment inserts on the pull-off force of implant-retained overdentures – A laboratory study

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Abstract

Objectives: The aim of the current study is to investigate the influence of mechanical stress as well as cleaning agents on the performance of various polyether ether ketone (PEEK) inserts for implant-retained overdentures (IOD).

Materials and Methods: Three different standard PEEK inserts were subjected to rapid artificial aging through storage in chemical denture cleaning agents (acetic acid, sodium hypochlorite, or sparkling denture cleaner) as well as demineralized water. The pre-aged PEEK inserts were then placed in *unilateral* IOD and subjected to 200,000 chewing loads (5 kg ~ 50 N), with 5000 thermal cycles (5/55°C), and 1100 removal/insertion cycles (vertical movement 2 mm).

Results: For all the PEEK inserts, the retention forces decreased significantly with an increasing number of mechanical load cycles and after exposure to all the cleaning agents. PEEK inserts aged by exposure to chemical cleaning agents showed a significantly higher decline in retention force than the inserts stored in water. Confocal laser scanning microscopy indicated that the decline in retention force might be caused by wear on the internal insert surface in contact with the patrix.

Conclusions: Within the limitations of this study, it can be concluded that the application of chemical cleaning agents accelerates the decline in the retention forces of PEEK retentive inserts in IODs.

KEYWORDS
chemical cleansing, chewing simulation, Novaloc®, polyaryl ether ketone, polyether ether ketone, retention force

1 | INTRODUCTION

Edentulism is the consequence of complete tooth loss (Aida, 2021), and it leads to the continuous resorption of the alveolar ridges (Crum & Rooney Jr, 1978; Taguchi et al., 1995). The conventional wisdom is that the continuous resorption of the alveolar ridge coincides with the decreasing retention of conventional complete dentures (CCDs) (Marcello-Machado et al., 2017). Moreover, significant correlations between the retention of a removable prosthetic restoration in edentulous patients and the prevention of diseases as well as an

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increased risk of mortality have been identified (Emami et al., 2013; Felton, 2016), which underlines the clinical relevance of sufficient denture retention. In patients with highly atrophic alveolar ridges, an improvement in denture retention can only be achieved with implant-retained overdentures (IOD), which also improve the quality of life (Jofre et al., 2013).

IODs are attached to osseointegrated implants (Fueki et al., 2007; Kutkut et al., 2018) and allow for higher bite force and chewing efficiency than CCDs (Fontijn-Tekamp et al., 2000; Han & Kim, 2016). IODs are regarded as a minimum implantological treatment option in edentulous patients and should be attached to at least two implants in the *interforaminal* region (Schwarz et al., 2016). IODs with solitary attachments also have distinct advantages in maintenance and reparability, because they are easier to clean than nonremovable implant-retained restorations or other implant prosthetic treatment options such as bars (Walton & MacEntee, 1993). Solitary attachments in IODs can be classified into magnetic, ball (e.g., Dalbo® System), and stud (e.g., Locator® or Novaloc®) attachment systems. The requirements for attachments include minimal dimensions, sufficient retention, low wear, and comfort in terms of handling, hygiene, and maintenance.

Stud attachment systems have several advantages over ball attachments, including simple handling as the matrix, and the insertion tool are independent from the implant system in use. Simple complications, such as a loss of retention or defects in the matrix and patrix, can commonly be corrected through the simple replacement of the various components. In addition, stud attachments require less vertical height than ball attachments (Büttel et al., 2009). Independent of the individual system employed, IODs and their attachments require relevant aftercare and maintenance (Meijer et al., 2004). With regard to retention, stud attachments decline significantly faster than ball attachments, which results in shorter intervals between clinical appointments and higher treatment costs (Sultana et al., 2017). In the past, inserts in stud attachments have been fabricated from nylon. In recent years, inserts made of polyether ketone (PEKK) or polyether ether ketone (PEEK) have been introduced to the dental market. PEEK is a semicrystalline, high-performance, thermoplastic polymer belonging to the polyaryl ether ketone (PAEK) family. These materials feature high biocompatibility, high tensile (elastic modulus up to 5000 MPa) and flexural strength (up to 215 MPa), and chemical resistance (Alexakou et al., 2019). In a recent laboratory study, PEEK inserts were compared with nylon-based inserts regarding wear and loss of retention in their dependence on abutment and implant angulation. While a loss of retention was observed in all the attachments, PEEK and PEKK inserts were superior to those fabricated from nylon after mechanical loading (Wichmann et al., 2020).

The IODs and CCDs are very similar in design and basic material, and they only differ in the additional implant-supported attachments. IODs feature a very large surface area, which offers a large interface that may be colonized by microorganisms. Cleaning this surface is essential, especially for patients with underlying diseases and compromised immune systems, to prevent local and systemic diseases that could lead to hospitalization (Günther et al., 2020). According to current studies, a combination of chemical and mechanical cleaning measures is most effective for removing biofilms (Schmutzler et al., 2021).

Against this background, the aim of the current study is to investigate the influence of mechanical stress as well as cleaning agents on the performance of various PEEK inserts from the Novaloc® attachment system. The working hypotheses are as follows:

> Exposure to chemical denture cleaning agents produces a decline in the retention force of PEEK inserts.

2 | EXPERIMENTAL APPROACH

2.1 | Materials

In the present study, three different standard attachment inserts fabricated from a polyether ether ketone (PEEK; Novaloc® Retention Insert, Valoc AG, Rheinfelden, Switzerland) were examined. The three color-coded inserts differed in their retentive force and were either white, green, or blue (Table 1).

2.2 | Experimental procedure

The PEEK inserts were subjected to four distinct chemical cleaning protocols, including immersion in deionized water (control group). For the experiment, every test series included five inserts, which were stored in sodium hypochlorite, acetic acid, or deionized water (Table 2) at a temperature of 35°C for 180 consecutive cycles with a duration of 15 min each. Between each storage cycle, the inserts were washed in water (25°C) for 15 s. A fourth cleaning protocol involved the immersion of the test specimens in a commercial chemical denture cleaner (COREGA® TABS® Denture Cleanser) using an analogous protocol in which the

TABLE 1 Overview of the attachments analyzed in the current study.

Novaloc® retention insert	Code	Manufacturers	Retentive force	LOT
White	NW	All by Valoc AG, Rheinfelden, Switzerland	750 g	L0083685
Green	NG		1650 g	L0083872
Blue	NB		2100 g	L0083534

TABLE 2 Cleaning agents used in this study.

Cleaning agent	pH	Manufacturer
Deionized H_2O	-	-
(sparkling) COREGA® TABS® Denture Cleanser solution	7.2	Stafford-Miller Limited, Dungarvan, IR
5 wt.% H_3COOH (acetic acid)	2.4	Carl Roth GmbH + Co. KG, Karlsruhe, D
1 wt.% NaOCl (sodium hypochloride) solution	10.9	Carl Roth GmbH + Co. KG, Karlsruhe, D

solution was renewed after the cycles (180 cycles, duration 15 min each) to take full advantage of the sparkling effect. One representative from each group of cleaning solutions commonly used by patients was investigated in the current study. Representatives of household denture cleaning solutions included bicarbonates (COREGA® TABS®), acids (acetic acid), and hypochlorite (sodium hypochlorite). Acetic acid and the other cleaning solutions examined are regularly used for chemical denture cleaning in common oral hygiene protocols and have been investigated in studies examining the efficacy of denture cleansing with household products and commercial cleaning solutions. (Basson et al., 1992; Nanditha Kumar et al., 2012) As it is well-known that numerous elderly patients dilute highly concentrated acetic acid (up to 25%) with water to be use it as denture cleaning agent, a concentration of 5% was regarded as an adequate dilution approach.

A model experimental setup was developed to simulate a section of a lower jaw with a *unilateral* IOD to be mounted in a chewing simulator and a universal testing machine. Each model included a *unilateral* IOD (3D-printed, polymethylmethacrylate (PMMA; V-Print dentbase, VOCO GmbH, Cuxhaven, Germany) in the third quadrant, with PMMA-teeth from 31 to 36 (PMMA 3D-printed, V-Print dentbase) and tooth 37 fabricated from zirconium dioxide (ZrO_2; VITA YZ® HT, A1, VITA Zahnfabrik, H. Rauter GmbH & Co. KG, Bad Säckingen, Germany).

The retention insert of the Novaloc® attachment system used for the attachments in the current study includes a PEEK matrix housing and a carbon-coated titanium patrix abutment (Straumann AG, Basel, Switzerland). For the experimental setup in the current study, implant analogs (Straumann AG, Basel, Switzerland) were inserted in region 033 of the *hemifacial mandibular* model (plaster Type IV, Octa-stone M, Kulzer GmbH, Hanau, Germany). The contact area between the IOD base and the plaster model was covered with a *gingival* manchette (HS-A-Silikon light body, Henry Schein Dental Deutschland GmbH, Langen, Germany). In the area of tooth 33, a screw was polymerized into the IOD, which enabled insertion and removal movements as well as retention measurements on the universal testing machine (Figure 2, left). Tooth 37 of the IOD was the antagonist of the enstatite balls (Ø 6 mm, CeramTec GmbH, Plochingen, Germany) attached to the chewing simulator, which simulated a chewing load in the *posterior* area, causing maximum insertion of the IOD into the *gingival* tissues and leverage on the PEEK insert and patrix. The samples were clamped in a sample pot and placed in one of the eight floodable and waterproof chambers of a commercial chewing simulator.

Each insert (NW, NG, and NB) was chemically pretreated according to the cleaning protocols. After artificial aging, the inserts were placed in the IODs, *uniaxial* and *extra-axial* chewing forces were then applied in the area of tooth 37, and down-and-up movements were performed in the area of tooth 33 to simulate mechanical stress on the inserts (Figure 2, right).

The chewing simulator (CS-4.8, SD Mechatronik GmbH, Feldkirchen-Westerham, Germany) was modified to simulate chewing movements as well as denture insertion and removal. A total

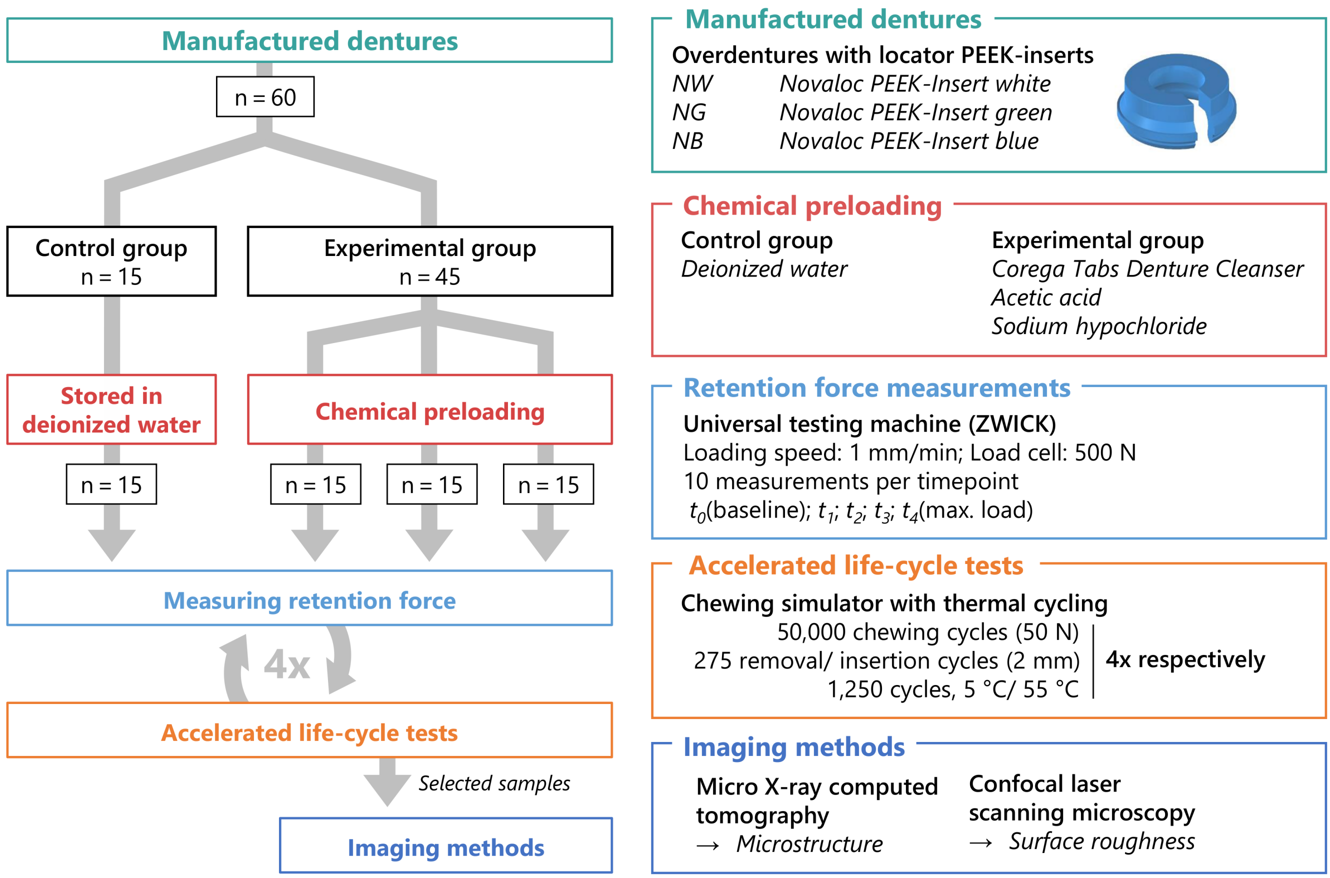

FIGURE 1 Flow chart and experimental approach.

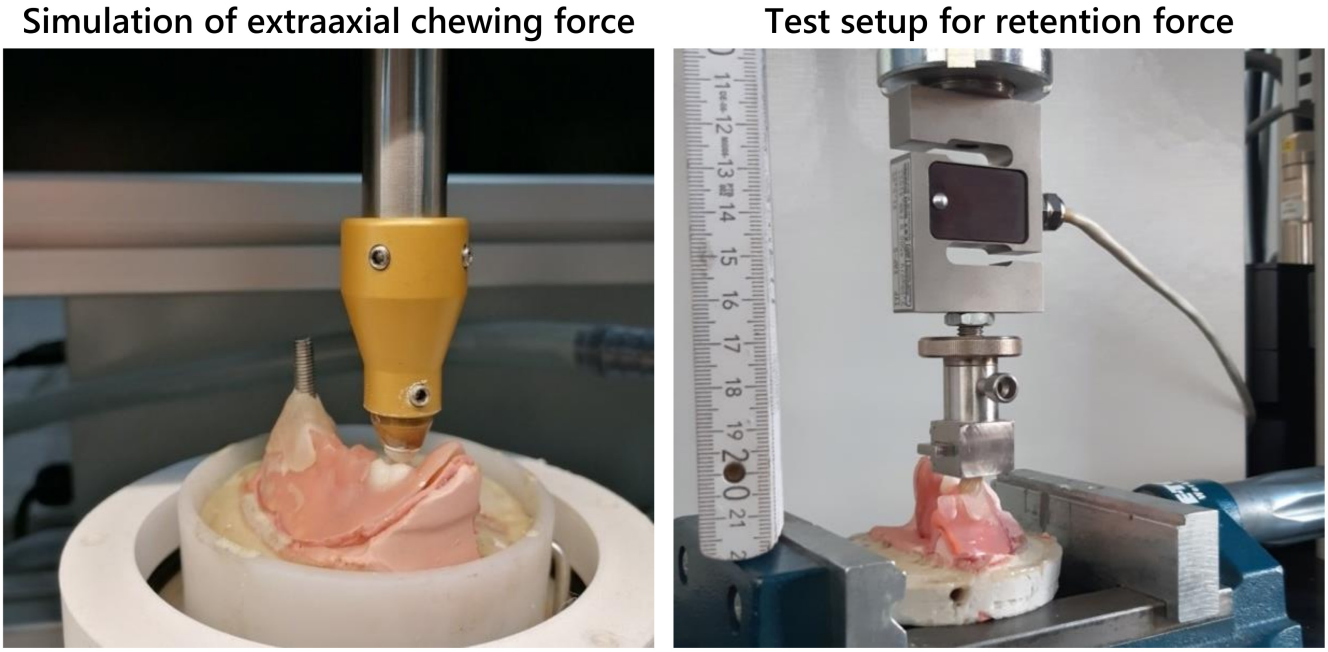

FIGURE 2 Left: IOD during chewing simulation of extra-axial chewing force (area tooth 36). The screw included for insertion and removal is visible in the background; right: Test setup universal test machine with small load cell (500 N) and load suspension tool.

of 200,000 chewing loads (5 kg ~ 50 N, vertical movement 1 mm), including 5000 thermal cycling units (5/55°C) and 1100 removal/insertion cycles (vertical movement 2 mm) were simulated in five samples of every series, which is equivalent to 1 year of clinical service (Besimo & Guarneri, 2003; Kern et al., 1999). An overview of the experimental procedure is displayed in Figure 1.

3 | ANALYTICAL METHODS

3.1 | Mechanics

After 50,000 loads, including 1250 thermal cycles and 275 removal/insertion cycles, the retention forces were measured 10 times for every sample with a universal testing machine (ZwickRoell Retroline, ZwickRoell, Ulm, Germany). To achieve reproducible values with low scatter, a small load cell (500 N) with a self-developed load tool was used. The force was increased with a loading speed of 1 mm/min until reaching the maximum.

3.2 | Imaging methods

Micro X-ray computer tomography (μXCT) was used to visualize the structure of the attachments, including the PEEK matrix housing (Straumann AG) and the carbon-coated titanium patrix (Straumann AG). The modular industrial tomography was equipped with an X-ray reflection tube (FXE 225.99 with a tungsten target and a focal spot Ø 0.6 μm, YXLON International GmbH) and 2D-detector 1621 N (2048 × 2048 pitches; PerkinElmer Inc). A resolution of 4.88 μm was achieved.

Exemplified for the blue inserts, confocal laser scanning microscopy (CLSM) was used to investigate the surface texture at t0 and t4, for the groups with chemical pretreatment as well as the reference group (deionized water) and an additional group of unstressed retention inserts (no applied load). One measurement was made for each retention insert (n = 4 per group) with a Keyence VK-X1000/1050 (Keyence Deutschland GmbH) equipped with a Nikon CF IC EPI Plan 50x objective (NA: 0.55, WD: 8.7 mm, NIKON, Osaka, Japan) and a red laser (λ = 661 nm). The surface areas were analyzed for the arithmetical mean height (Sa) and the surface texture aspect ratio (Str) at two positions (edge and central region, 130 × 200 μm each) within the retention inserts using Multi File Analyzer software (2.1.3.89, Keyence Deutschland GmbH, Neu-Isenburg, Germany) according to ISO 25178 under appropriate filtering (S-filter: 1 μm; F-filter: degree 2 polynomial; filter-type: double Gaussian; end-effect correction). While the Sa value describes a general mean height of the surface in μm, the Str value represents a score for the uniformity of the surface, according to which a high value (Str = 1) represents an irregular or isotropic surface and a low value (Str = 0) reflects a uniform texture, for example, with regular, parallel linear profiles.

3.3 | Statistics

The calculation of mean values and standard deviations (SD) for the measured retention forces, the visualization by boxplots, and statistical tests were performed using statistical analysis software (IBM SPSS Statistics 29.0.0.0). Shapiro–Wilk test did not find continuous normality of the distribution of retention force data, after which an aligned rank transformation was performed (ARTool 2.1.2)

(Wobbrock et al., 2011). Subsequently, the data were subjected to a three-way ANOVA with the factors retention insert, chemical pretreatment, and timepoint. Differences in mean retention forces for the separate timepoints were analyzed by Kruskal–Wallis test with Bonferroni correction for post hoc multiple comparisons. The level of significance (α) was set to 0.05.

4 | RESULTS

4.1 | Retention force

The results of the descriptive analyses are displayed in Table 3 and Figure 3. A significant decrease in retention forces between the baseline (t_0) and maximum load (t_4) was observed for all PEEK inserts exposed to chemical cleaning agents ($p < 0.001$) as well as, although less pronounced, for storage in deionized water as the control group ($p < 0.05$) (Table 4). According to the ANOVA, the influence of all factors was significant ($p < 0.001$). The influence of the retention insert (NW, NG, and NB) was highest, followed by the timepoints (t0, t1, t2, t3, t4), and the chemical pretreatment (deionized water, COREGA® TABS®, acetic acid, sodium hypochlorite) with the smallest influence.

4.2 | Imaging analysis

Cross-section images from the µXCT measurements show the PEEK inserts (2 in Figure 4, gray values), which closely fit the carbon-coated titanium patrix (3 in Figure 4, bright gray values). Between the PEEK insert and the matrix housing, an annular gap with a maximum thickness of 120 µm can be identified. During the removal/insertion procedure, the PEEK inserts move over the rounding of the patrix as a result of the deformation in the area of the gap. The surface texture of this region of interest (ROI) in the PEEK insert was investigated using CLSM.

The exemplary measurement of the surface roughness for the PEEK inserts (NB) qualitatively showed wear on the surface of the retention area based on the surface renderings (Figure 5). In contrast to the central region, a reduction in the surface roughness for the edge region could be detected based on the Sa values determined both for the control group during water storage and as a result of all chemical pretreatments. Based on the Str, tendencies could be observed that the value for the areas of the edge region was larger for the groups with chemical pretreatment, both in the mean and the SD. No obvious difference resulting from the different storage protocols could be observed (Table 5).

5 | DISCUSSION

5.1 | Exposure to chemical denture cleaning agents produces a decline in the retention forces of PEEK inserts

The retention forces of the various inserts in the control group measured in the current study were close to the values specified by the manufacturer. The white insert (NW) featured an average

TABLE 3 Retention force (mean ± SD / N) of the PEEK inserts after mechanical aging with respective chemical pretreatment.

Retention insert	Timepoint	Retention force (mean ± SD)/N H_2O deionized	COREGA® TABS® solution	Acetic acid	Sodium hypochlorite
NW	*t0* (baseline)	6.9 ± 1.4	9.4 ± 0.7	7.9 ± 1.4	8.6 ± 0.7
	t1	7.3 ± 1.5	8.7 ± 1.1	6 8 ± 1.8	7.6 ± 0.6
	t2	5.6 ± 1.2	7.7 ± 1.1	6.9 ± 1.4	7.0 ± 0.7
	t3	5.7 ± 1.6	7.3 ± 1.1	5.3 ± 1.3	7.0 ± 0.8
	t4 (max. load)	5.9 ± 1.3	6.4 ± 1.7	4.9 ± 1.3	6.8 ± 0.5
	ΔE (t0/t4)	15%	31%	38%	21%
NG	*t0* (baseline)	19.3 ± 2.0	20.8 ± 1.7	16.1 ± 1.2	17.3 ± 1.2
	t1	17.1 ± 1.4	19.0 ± 2.2	16.5 ± 3.0	15.8 ± 2.3
	t2	17.8 ± 0.9	17.3 ± 2.5	14.5 ± 1.1	13.6 ± 2.5
	t3	17.8 ± 0.6	16.7 ± 2.7	14.4 ± 2.1	12.9 ± 2.4
	t4 (max. load)	18.0 ± 1.1	16.6 ± 2.1	14.4 ± 1.7	13.3 ± 2.6
	ΔE (t0/t4)	7%	20%	11%	23%
NB	*t0* (baseline)	21.1 ± 2.1	23.0 ± 1.4	22.2 ± 1.7	23.6 ± 1.1
	t1	19.8 ± 1.1	20.1 ± 1.8	20.8 ± 1.7	20.5 ± 2.6
	t2	19.3 ± 1.8	18.5 ± 2.4	21.0 ± 2.0	17.4 ± 3.4
	t3	19.0 ± 1.4	18.1 ± 3.4	19.7 ± 2.1	17.0 ± 3.5
	t4 (max. load)	19.6 ± 1.6	17.5 ± 3.1	16.9 ± 1.7	17.1 ± 3.0
	ΔE (t0/t4)	7%	24%	24%	28%

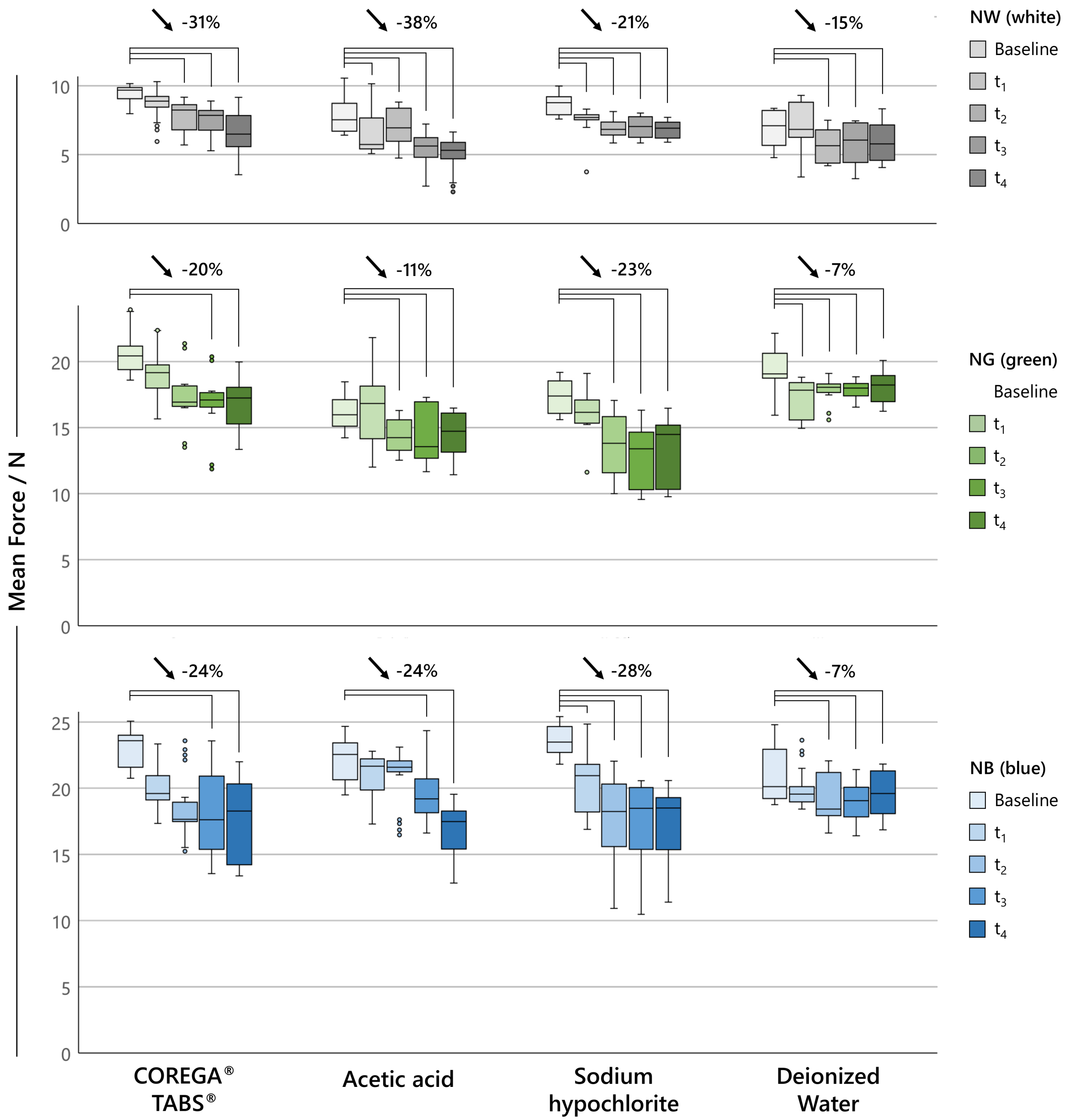

FIGURE 3 Influence of chemical treatment and mechanical aging on the mean retention forces (in N) achieved with white, green, and blue PEEK inserts. Error bars: ±2 standard error; Arrow indicates the difference in mean force (N) between the baseline and t4 (max. load). * indicates a significant difference ($p < 0.05$) between the baseline and respective timepoint within the chemical pretreatment and retention insert.

TABLE 4 Results of the three-way ANOVA.

Factor	F-value	p-value
Retention insert	4940.28	<0.001
Chemical pretreatment	138.21	<0.001
Timepoint	336.32	<0.001

initial retention force of 6.9 ± 1.4 N (manufacturer's specifications 750 g = 7.4 N), with green inserts (NG) at 19.3 ± 2.0 N (manufacturer's specifications 1650 g = 16.2 N), and blue inserts (NB) at 21.1 ± 2.1 N (manufacturer's specifications 2100 g = 20.6 N).

Even though in this study the pre-storage in denture cleaning agents had a significant influence on the individual retention

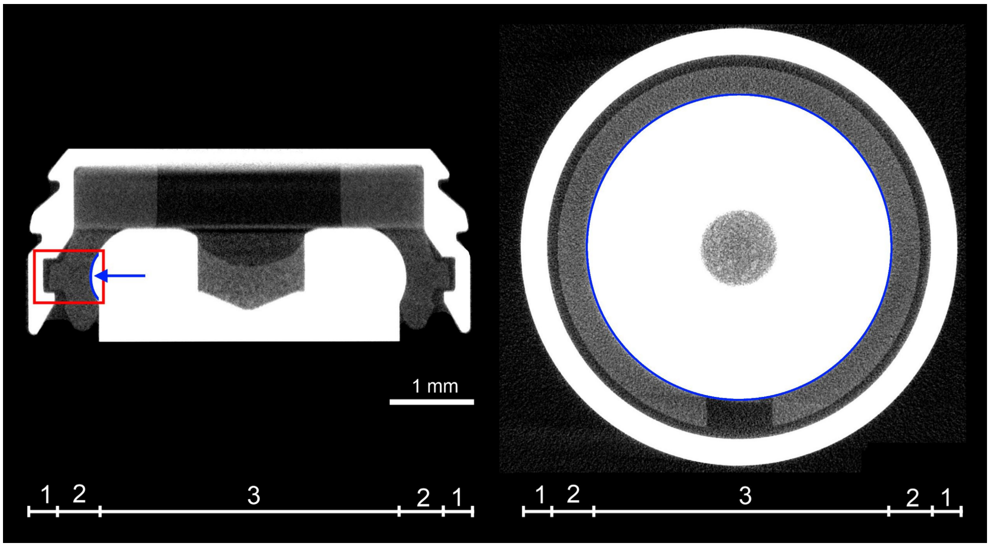

FIGURE 4 µXCT image of the longitudinal cross section (left) and the cross section with 1 - housing, 2 - insert and 3 - patrix; red marked area, deforming region of PEEK inserts (gray pixels) while insertion and removal movement, blue marked region of interest (ROI) was analyzed by CLSM.

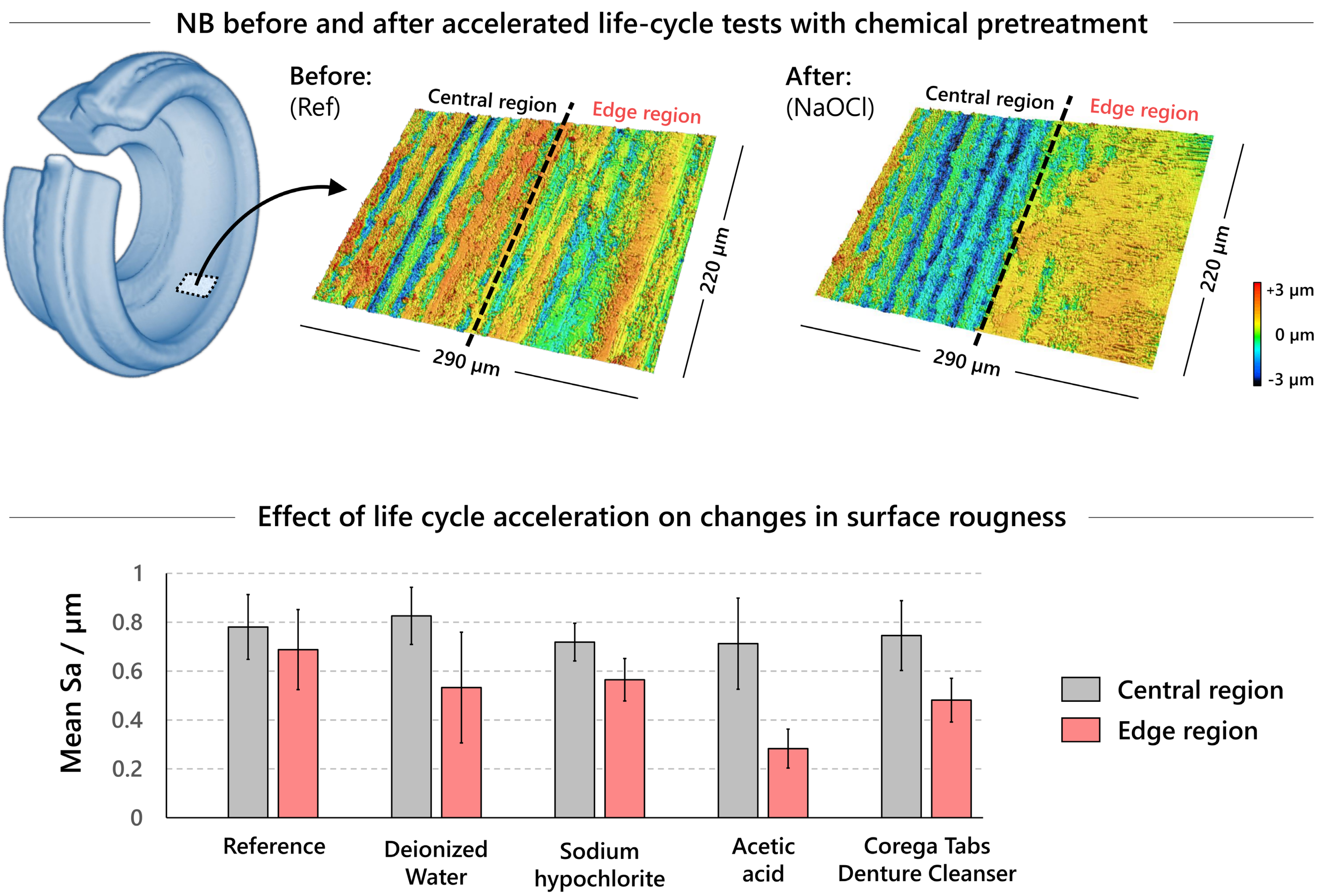

FIGURE 5 Exemplary analysis on the surface roughness of the blue PEEK inserts in the region stressed by mechanical aging; top: Qualitative evaluation on the damaged surface morphology and subdivision of the analysis according to the stress damage of the PEEK inserts; and bottom: Quantitative analysis of the arithmetical mean height (Sa) based on the applied agents in comparison to the surface roughness of a novel PEEK insert (reference).

Group	Central region		Edge region	
	Sa/µm	Str	Sa/µm	Str
No applied load	0.78 ± 0.13	0,08 ± 0,08	0.69 ± 0.16	0,13 ± 0,13
H_2O deionized	0.83 ± 0.12	0,06 ± 0,01	0.53 ± 0.23	0,08 ± 0,02
COREGA® TABS® solution	0.72 ± 0.08	0,14 ± 0,06	0.56 ± 0.09	0,33 ± 0,27
Acetic acid	0.71 ± 0.19	0,04 ± 0,01	0.28 ± 0.08	0,37 ± 0,16
Sodium hypochlorite	0.75 ± 0.14	0,08 ± 0,01	0.48 ± 0.09	0,30 ± 0,21

TABLE 5 Mean and SD values for the Sa (arithmetical mean height) and Str (texture aspect ratio) of the blue PEEK inserts depending on the chemical cleaning employed agents and in comparison to a novel blue PEEK insert (reference).

force, the influence was subordinate to the respective retention inserts (NW, NG, and NB) and the number of simulated cleaning intervals. The conventional wisdom is that the minimum retention force of an attachment should exceed 5 N to ensure secure retention and the stability of overdentures (Yamada et al., 1978). In the current study, almost all inserts survived chemical pre-storage and mechanical stress without total failure and featured higher retention forces both prior to and after the stress tests than the above 5 N threshold (Figure 3). Lower values (4.9 N) were only identified for inserts with the lowest retention forces (NW) that had been pre-stored in acetic acid and after artificial aging (Table 3).

Regarding the removal of biofilms, sodium hypochlorite (NaOCl), and sodium hypochlorite-based denture cleaners are reportedly the most effective agents (Badaró et al., 2020; Jose et al., 2010; Valentini-Mioso et al., 2019). The data from the current study suggest that none of the analyzed denture cleaning agents is superior for avoiding a loss of retention forces. For the white inserts, acetic acid produced the highest decline in retention forces (NW_HAc = −38%), while for the green and blue inserts, it was sodium hypochlorite (NG_NaOCl = −23%; NB_NaOCl = −28%).

Several publications have shown that additional mechanical cleaning (with a tooth or denture brush) leads to a significantly improved removal of biofilms compared with chemical cleaning of the dentures alone, which is why a combination of chemical and mechanical cleaning is recommended (Mylonas et al., 2022; Schmutzler et al., 2021; Valentini-Mioso et al., 2019). Thus, further studies should consider a combination of mechanical cleaning and chemical pre-storage to address their effects on retention forces. NaOCl may, however, corrode the metals used in denture fabrication (Mylonas et al., 2022), which might lead to the corrosion of the metal housing of the attachment matrix. This correlation could be evaluated in a study in which the entire denture is soaked in the cleaning solution, in contrast to the experimental design employed in this study. The experiment included only retention rings made of PEEK, which were examined for chemical–mechanical aging. Further studies might address competing material representatives that are commonly used in retention rings, including nylon. These results should be compared with those of the PEEK rings to find out which material should be preferentially used in terms of chemical–mechanical aging.

5.2 | Thesis on the mechanism of action

The authors assume that a supporting function for the retention of the inserts is provided by the microstructural texturing of the inner surfaces by transversal linear profiles with a specific height of approximately 5 µm (Figure 5). In the current study, the wear of these profiles was observed as a result of the applied load, in which the edge region experienced stronger changes indicated by a reduced mean height of the entire surfaces, as well as an increasing texture aspect ratio, which is indicative of the reduction of the linear height profiles within the retentions insert. In addition, it is assumed that the surface of the edge regions of the inserts is mechanically stressed more clearly by friction than the central region when the prosthesis is pulled off and pressed onto the patrix (Figure 4). The lack of roughness reduction in the central region suggests that the media itself does not affect the roughness. The significant difference in the decreasing retention forces between deionized water and the chemical denture cleaning agents suggests that the micromechanical properties in the edge region of PEEK inserts have deteriorated due to the cleaning agents. Since the edge regions were subjected to higher mechanical stress, the changes in roughness were more distinct than in the central regions that had been also subjected to chemical stress. The increased roughness of the PEEK inserts results in a higher specific surface area and thus presumably increased reactivity with the chemical medium.

5.3 | Clinical relevance

In the present study, all cleaning solutions significantly caused aging of the PEEK retention rings. Nevertheless, no specific cleaning agent can be recommended from an artificial aging perspective. Against this background, further investigation of other denture materials and retention ring materials, such as nylon and PMMA, would be useful.

5.4 | Limitations of the experimental procedure and measuring method

Limitations of the current study include that only the effects of acid-, bleach-, and bicarbonate-based dry cleaning solutions were analyzed. In addition, surface texture was not investigated for all specimens, but only for individual representatives.

Since it was not possible to position the dentures absolutely identically in the chewing simulator, the different loads on the PEEK inserts contributed to different surface changes on the inner surfaces and thus to higher scatter in the retention forces. For example, despite a specially designed loading device designed to apply only vertical forces, the orientation of the prosthesis had a (most likely minor) effect on the resulting retention forces.

Measurements of surface roughness were only possible through the lateral opening of the insert. In contrast to flat specimens, the analysis of concave shaped surfaces required appropriate filters, which caused a slight distortion of the reproduced surfaces and thus affected the surface roughness measurements. The number of samples forwarded to CLSM was insufficient to perform adequate statistical analysis. Therefore, the results reported in this study are based on an estimate and require statistical validation with a larger sample size.

All results and derived discussions refer to the products (Table 1) and strains (Section 2) used in the current study.

6 | CONCLUSION

The data from the current laboratory study underline the detrimental effect of chemical denture cleaning solutions and mechanical loading on the retention force of PEEK inserts. The loss of retention force was higher when the PEEK inserts were stored in chemical cleaning solutions prior to mechanical loading. Confocal laser scanning microscopy suggested that the decrease in retention forces might be caused by wear on the internal surface area of the inserts in contact with the matrix. Frequent application of chemical denture cleaning agents might promote retention loss and increase the frequency of maintenance measures.

In conclusion, chemical–mechanical denture cleaning is necessary, but it should be emphasized that cleaning has an effect on the denture materials; in this case, PEEK.

AUTHOR CONTRIBUTIONS

A.K.: conceptualization, investigation, formal analysis, visualization, writing - original draft, writing - review & editing, supervision, resources and project administration// L.R.: investigation, formal analysis, visualization, writing - original draft, writing - review & editing, and project administration// F.F.: investigation, visualization, writing - original draft, and writing - review & editing// S.S.: writing - original draft and writing - review & editing// B.L.: writing - original draft, writing - review & editing and project administration// S.H.: conceptualization, writing - original draft, writing - review & editing and project administration.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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