WHITE PAPER

Microplastic Release from Orthodontic Retainers During Simulated Wear

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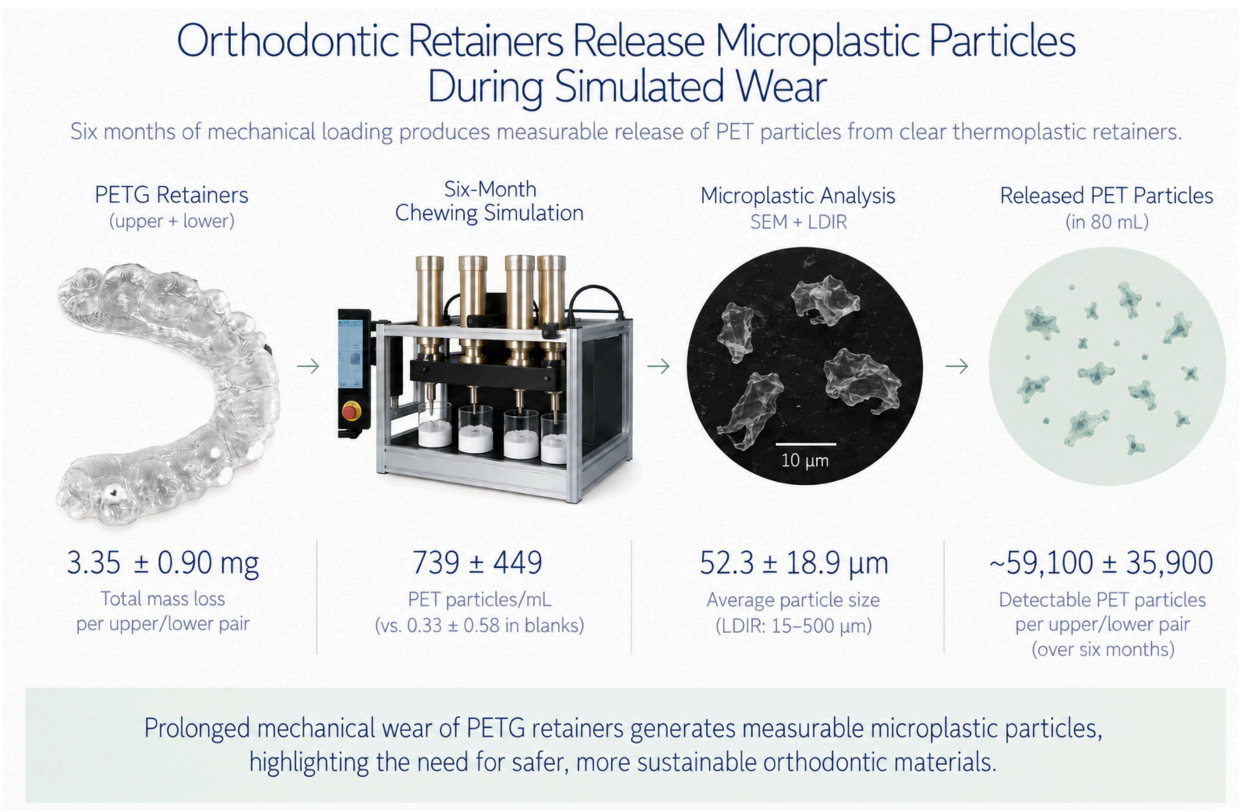

Executive Summary

Thermoplastic orthodontic retainers are worn for prolonged periods and may represent an overlooked source of microplastic exposure. To quantify particle release during extended wear, PETG retainers were subjected to 58,240 cycles of simulated chewing, representing approximately six months of nighttime wear under mechanical loading. Following testing, retainers lost an average of 3.35 ± 0.90 mg per upper/lower specimen pair, while LDIR analysis detected 739 ± 449 PETG particles/mL (≥15 μm, the lower detection limit of the method) in the resulting effluent, corresponding to approximately 59,100 ± 35,900 detectable particles per specimen pair, with an average diameter of 52.3 ± 18.9 μm. These findings demonstrate measurable microplastic release from PETG retainers during prolonged simulated wear and highlight the importance of considering particle generation of orthodontic appliances.

1 Background and Rationale

Microplastics have been detected in our air, our food, and our water.[1] As a result of the ubiquity of microplastic contamination, it comes as no surprise that these small particles have entered our bodies. Liver, kidneys, blood, placenta, and sperm are just a few of the human organs and bodily fluids that have detectable quantities of microplastics.[2] Although challenging to estimate a universally applicable annual exposure quantity for microplastic ingestion, Cox *et al.* endeavored to calculate this by combining published microplastic concentrations in commonly consumed foods, beverages, water, and air with U.S. consumption and respiration data.[3] When inhalation is included, the authors estimate 74,000-121,000 microplastics are consumed by the average American annually.[3]

An overlooked potential exposure pathway for many Americans is the use of thermoplastic oral appliances such as clear orthodontic aligners and retainers. Following orthodontic treatment, retention is prescribed for virtually every patient to prevent tooth movement and relapse, and clear thermoformed thermoplastic retainers (typically made of PETG) are among the most commonly prescribed retention appliances.[4] Because retainers are prescribed for long-term or even lifelong wear, these materials can remain in repeated contact with the oral environment for years. In a survey of specialist orthodontists, 67–78% recommended lifetime retainer wear.[5] Recent studies have raised questions about whether this prolonged exposure may also represent a source of microplastics.

In 2024, Quinzi *et al.* took seven brands of aligners, placed them in artificial saliva, and subjected them to 7 days of stirring (5h/day).[6] The artificial saliva was analyzed spectroscopically and 5-20 microplastics were detected.[6] Another study had a similar protocol where the researchers vortexed pieces of aligners in artificial saliva and vortexed 30s per day for 7 days to simulate dental microplastic release.[7] Flow cytometry analysis revealed thousands of particles (2,559-7,403 particles for the thermoformed materials.)[7] Recently, a group of researchers mounted aligners on resin dental casts and subjected them to cyclic 50 N compressive loading in artificial saliva to simulate repeated occlusal forces during swallowing under oral conditions. Optical microscopy showed apparent detachment of microplastics from all aligners tested in the study.[8]

Although these preliminary studies demonstrate that microplastic particles detach from orthodontic aligner materials under mechanical agitation, the extent of particle release over longer-term use remains unclear. To better characterize this exposure over a clinically relevant wear period and under mechanical loading, we subjected passive orthodontic trays (retainers) to six months of simulated chewing and quantified the particles released.

2 Materials and Methods

Retainer Fabrication

A dental model of 3 posterior molars of both an upper and lower tray was 3D printed using FormLabs Fast Model Resin on a Form 4 SLA printer. The model was washed with isopropanol for 10 min in the FormWash, left to air-dry, and followed by a short final cure (1 min) in the FormCure.

PETG retainers were fabricated using Great Lakes Clear Splint Biocryl 1mm/125mm - Round discs. These discs were thermoformed over the dental models for the recommended amount of time (35s) using a MiniSTAR S positive pressure thermoformer. The produced retainers were then cut down first using scissors and then trimmed to a scalloped edge using a carbide bur from Great Lakes and a rotary tool. The edge was then finished using a Great Lakes Super Gold 1" Finishing Buff - Medium. Four sets of trays were produced.

Specimens were sprayed with oil-free air for 5s before weighing with an analytical balance and imaged before chewing simulation.

Six-Month Chewing Simulation

An SD Mechatronik Chewing Simulator at the University at Buffalo School of Dental Medicine Materials Testing Facility was used. 80 mL of HPLC water from glass bottles procured from J.T. Baker was used in place of artificial saliva in each chewing sample chamber (Fig. 1). This was decided due to ease of characterization of the resulting effluent. Each chewing sample chamber held a matched upper and lower retainer mounted onto a model, each covering three posterior teeth.

58,240 cycles (approximately 6 months of wear 12h/night),[9] 37 ℃ chewing sample chamber temperature for “saliva” during testing, 5kg (49 N) vertical load per chewing sample chamber to approximate normal mastication.

After chewing simulation, specimens were rinsed with HPLC-grade water and air-dried for at least 24 hours under inverted aluminum weigh boats to protect them from airborne contamination. They were then weighed and imaged. “Saliva” effluent was vortexed for 5s in chewing sample chambers, then transferred to glass jars with aluminum foil seals (both first sprayed with oil free air for 5s). A chewing simulation blank was also performed where one chewing sample chamber ran with 80 mL of HPLC water and no retainers.

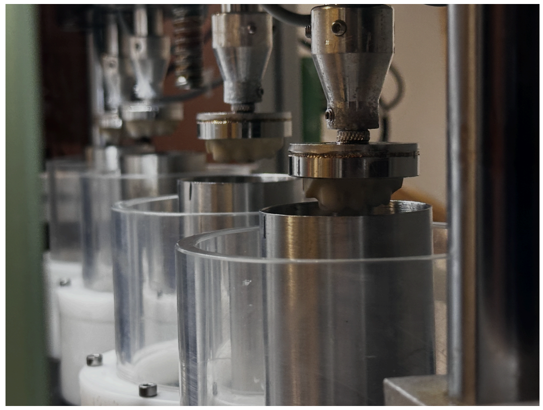

Figure 1. Chewing simulation chambers.

Microplastic Analysis

1 effluent of chewing simulator blank, 1 effluent of PETG chewing simulation, and an HPLC water control sample were sent for scanning electron microscopy (SEM) analysis with Covalent testing labs. SEM was performed using a JEOL JSM-IT800 field emission scanning electron microscope. Secondary electron images were acquired at an accelerating voltage of 5.0 kV over a magnification range of 43x to 10,000x with a working distance maintained at approximately 10 mm. SEM analysis was performed to qualify the average particle size so we could determine the best characterization technique.

3 effluents of chewing simulator blanks, 3 effluents of PETG chewing simulation, and an HPLC water control sample were sent for Laser Direct Infrared microscopy (LDIR) microplastic analysis at Light Labs. LDIR was performed using an Agilent 8700 LDIR and the data was returned as a certificate of analysis.

3 Results

Retainer Changes Following Six-Month Simulated Wear

Noticeable wear was seen on all 4 specimens of PETG retainers (Fig. 2). Following six months of simulated wear, PETG specimens exhibited an average total mass loss of 3.35 ± 0.90 mg per upper/lower specimen pair (n = 4) (Table 1). SEM analysis of chewing-simulation effluent confirmed the presence of particulate matter and was used to get a qualitative sense of the size range of particles generated during simulated wear. Representative micrographs are shown in Fig. 3. Particle size and morphology varied significantly across samples. All samples contained particles, although the effluent of PETG chewing simulation was the most concentrated. PETG particles were generally rounder than those found in the blank samples. See Table 2 for tabulated particle size data.

Because the average particle size was generally >15 µm from SEM data, LDIR was determined to be an effective method to quantify and characterize the particles. Following 58,240 cycles of simulated wear, an average of 739 ± 449 PETG particles/mL were identified in the chewing-simulation effluent compared with 0.33 ± 0.58 particles/mL in chewing simulation blank effluent (Table 3). The average particle size of PETG detected was 52.3 ± 18.9 µm.

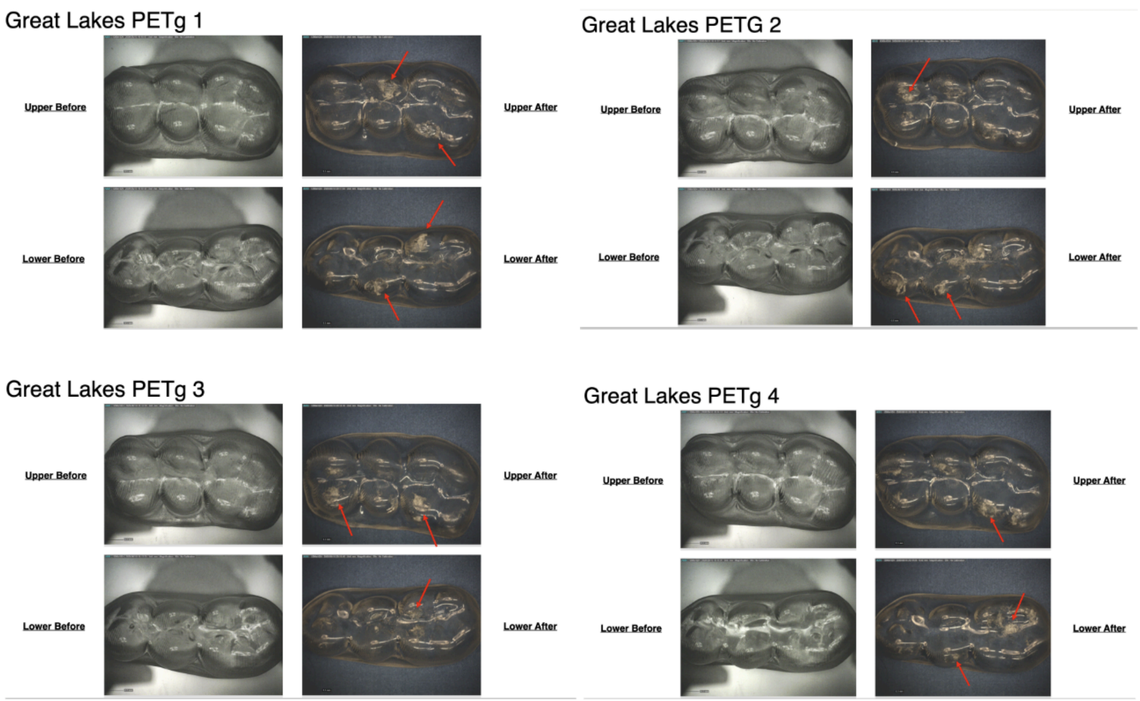

Figure 2. Images of before and after chewing simulation of PETG retainer specimens.

Table 1. Mass loss of each specimen following six-month chewing simulation.

Specimen	Upper Initial Mass (g)	Upper Mass Loss (mg)	Lower Initial Mass (g)	Lower Mass Loss (mg)	Total Mass Loss (mg)
PETG 1	0.5191	1.8	0.4683	1.7	**3.5**
PETG 2	0.4813	2.5	0.4635	1.9	**4.4**
PETG 3*	0.4835	0.7	0.4699	1.5	**2.2**
PETG 4	0.4848	1.2	0.4368	2.1	**3.3**
Mean ± SD	—	**1.55 ± 0.78**	—	**1.80 ± 0.26**	**3.35 ± 0.90**

**antagonist disconnected during testing*

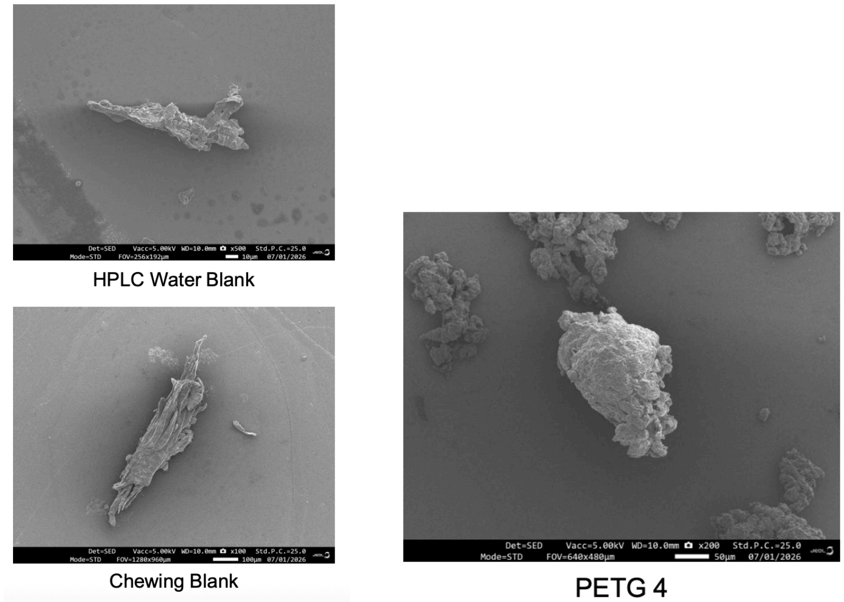

Figure 3. Representative SEM images of blank/controls and PETG chewing-simulation effluent.

Table 2. Particle dimensions observed by SEM.

Sample	Site 1 (µm)	Site 2 (µm)	Site 3 (µm)
HPLC Water Blank	193.9*	66.73, 133.2, 28.02, 23.91	126.9*
Chewing Blank	853.2, 117.8	9.601, 27.15, 58.32, 12.87	317.2, 88.08
PETG 4	728.6, 166.9, 88.82, 112.5, 263.9, 163.2, 306.9, 54.28	49.59, 83.37, 76.13, 194.8, 80.17	361.8, 99.18, 277.4, 374.6, 123.1

*Note: Values represent measured particle dimensions observed by SEM. *Some imaged areas contained only one visible particle.*

Table 3. LDIR particle counts in chewing-simulation effluent.

Sample	Replicate 1 (MPs/mL)	Replicate 2 (MPs/mL)	Replicate 3 (MPs/mL)	Mean ± SD (MPs/mL)
HPLC Water Blank	1	—	—	**—**
Chewing Simulation Blank	1	0	0	**0.33 ± 0.58**
PETG	1,065	926	227	**739 ± 449**

4 Discussion

This study demonstrates that orthodontic retainers subjected to prolonged simulated mechanical wear release measurable polymer particles into their surrounding medium. Following six months of chewing simulation, PETG specimens generated an average of 739 ± 449 PETG particles/mL, corresponding to approximately 59,100 ± 35,900 detectable PETG particles per upper/lower specimen pair in the 80 mL collection medium. The average diameter of detected PETG particles was 52.3 ± 18.9 μm. In comparison, chewing-simulation blanks contained 0.33 ± 0.58 PETG particles/mL, indicating that the PETG particle burden observed in the PETG samples was associated predominantly with wear of the test specimens rather than background contamination.

Importantly, LDIR analysis was limited to particles within the 15–500 μm analytical range; therefore, these values do not account for particles below 15 μm and should be interpreted as the number of detectable particles rather than total particle release. Based on linear extrapolation of the six-month simulated wear data, PETG retainers could release approximately 118,000 detectable PETG particles per year under equivalent wear conditions.

The detection of PETG particles following simulated wear is consistent with previous studies demonstrating microplastic release from orthodontic aligners. The present study extends these findings to a longer, six-month simulated wear period. Direct comparison between studies is limited by differences in materials, wear conditions, and analytical methods.

5 Limitations

This study was designed to simulate mechanical wear under controlled conditions and does not reproduce the full complexity of the human oral environment. HPLC-grade water was selected as the collection medium to facilitate subsequent particle characterization; consequently, the system did not include components of natural saliva, including proteins, enzymes, electrolytes, and other organic constituents. The simulation also did not account for the oral microbiome, food exposure, temperature and pH fluctuations, tooth brushing, retainer cleaning, insertion and removal, or other patient-specific behaviors that may affect material wear.

The relationship between the number of mechanical cycles and six months of clinical use was based on assumptions regarding nighttime wear. Actual mechanical loading varies substantially among individuals; therefore, the simulation should be considered a standardized wear model rather than an exact reproduction of six months of use by an individual patient.

Finally, gravimetric mass loss and LDIR particle counts represent complementary measures of wear but do not constitute a closed mass balance. Material lost from the specimens may include particles below the analytical detection limit, material remaining on experimental surfaces, or material not recovered during sample transfer. Accordingly, the measured specimen mass loss should not be assumed to correspond directly to the mass of particles quantified by LDIR.

6 Conclusion

Six months of simulated mechanical wear resulted in measurable microplastic release from PETG orthodontic retainers, demonstrating that particle generation occurs during prolonged use of passive oral appliances. However, particle release alone does not define potential exposure or persistence. An equally important question is what happens to these particles after they are released. Future work will expand the number of retainers evaluated to better characterize variability in particle release and investigate analytical approaches capable of detecting particles below the 15 µm size limit of the present study.

Acknowledgements

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