Original Article

Long-term effects of different cleaning methods on copolyester retainer properties

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ABSTRACT

Objective: To evaluate light transmittance, surface roughness, and flexural modulus of copolyester retainer material after long-term exposure to different cleaning methods.

Materials and Methods: Standardized copolyester retainer specimens (ACE) were subjected to seven chemical cleaning solutions for 6 months: Invisalign cleaning crystals, Retainer Brite, Polident, Listerine mouthwash, 2.5% acetic acid, 0.6% NaClO, and 3% H_2O_2. Seventy specimens ($n = 10$ per method, 50.8 mm $\times$ 12.7 mm $\times$ 1.0 mm) were exposed to the different solutions twice a week for 2 minutes or according to manufacturer's instructions and stored in artificial saliva at 37°C. Another group of specimens ($n = 10$) was brushed with a standardized toothbrushing machine for 2 minutes twice a week. At baseline and 6 months, light transmittance, surface roughness and flexural modulus of the specimens were quantified using spectrophotometry, profilometry, and three-point bend testing, respectively. Qualitative assessment was performed using scanning electron microscopy (SEM). Statistical analyses were accomplished at a significance level of .05.

Results: The results indicated that light transmittance through the specimens decreased significantly from baseline for all cleaning methods at 6 months. Flexural modulus of the specimens decreased significantly for all cleaning methods except Invisalign crystals and Retainer Brite ($P >$ .05). The Listerine group demonstrated the worst light transmittance change while H_2O_2 demonstrated the greatest change in flexural modulus of the specimens compared with other cleaning methods; however, no qualitative difference was observed using SEM analysis.

Conclusions: The results suggest that different cleaning methods affect long-term physical properties of the ACE retainer material. At the present time, none of these cleaning methods is ideal for copolyester retainer material. (*Angle Orthod.* 2019;89:221–227.)

KEY WORDS: Essix ACE; Thermoplastic retainer; Retainer cleaning; Physical property; Translucency; Flexibility

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INTRODUCTION

Retention is a critical aspect of overall orthodontic treatment.[1] Relapse is defined as any change in tooth position or arch form or relationship that occurs during the posttreatment period. The actual causes of relapse are unclear. However, four possible causes have been suggested: elastic relapse of the periodontal tissues, pressures exerted from the facial and oral soft tissues, occlusal forces, and post-treatment facial growth and development.[2]

The postretention phase of treatment continues for the patients' lifetime, and orthodontic retainers are required to compensate for the ongoing changes during this phase.[3] Thermoplastic vacuum-formed retainers have increased in popularity due to their esthetic and translucent properties.[4] Though often preferred because of their translucent nature, the

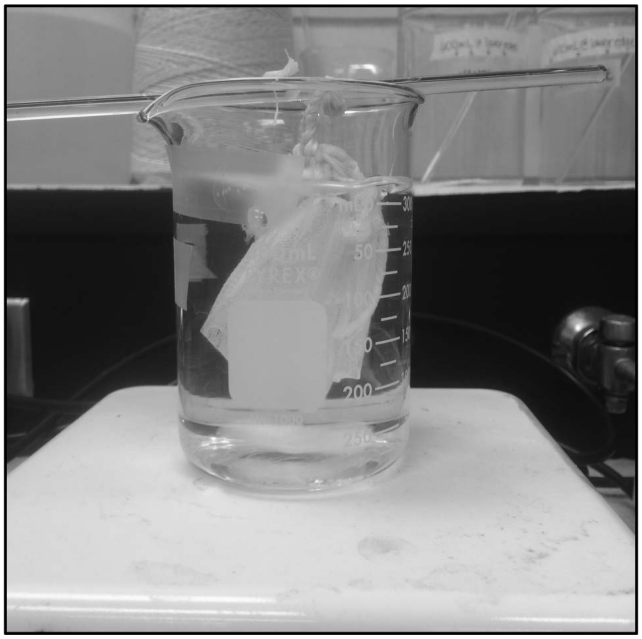

Figure 1. Specimens submerged in a cleaning solution on a magnetic stir plate.

physical properties of these translucent retainers undergo constant transformation due to intraoral temperature and load deflection changes.[5] A vacuum machine adapts heat-softened plastic by negative pressure, creating a vacuum that pulls the plastic onto a working study cast.

The two most common materials used for vacuum-formed retainers are polyethylene copolymers and polypropylene polymers. Polyethylene polymers are considered more esthetic because the material is virtually transparent. Polypropylene/ethylene copolymers are considered more durable and flexible,[6] but esthetically they are inferior to polyethylene because the polyethylene material is translucent. Polyethylene polymers also wear less than the polypropylene material.[7] In response to these issues, Dentsply International released Essix ACE retainer material (Dentsply GAC, York, Pa), the major composition of which is 95% copolyester and 5% trade secret.[8] Several studies have reported the effects of cleaning methods on the reduction of microbial deposition on the retainers.[9,10] However, there is no report regarding long-term effects on the material properties. The only study on long-term effects of cleaning methods on the physical properties of retainer material was investigated on polyurethane material.[11]

The objective of this study was to evaluate the long-term changes in light transmittance, surface roughness, and flexural modulus of Essix ACE, a copolyester retainer material using eight different cleaning methods over a 6-month period: Invisalign cleaning crystals (Align Technology, Inc, San Jose, Calif), Retainer Brite (Dentsply GAC, York, Pa), Polident (GlaxoSmithKline , Brentford, United Kingdom), Listerine mouthwash (Johnson and Johnson , New Brunswick, NJ), 2.5% vinegar, 0.6% sodium hypochlorite, 3% hydrogen peroxide, and toothbrushing with distilled water. Mean differences from baseline to 6 months were calculated by subtracting baseline values from 6-month values.

MATERIALS AND METHODS

Copolyester retainer material (Essix ACE) specimens ($n = 80$) were first heated and then vacuum-formed over a stainless-steel block with the dimensions of 55 mm $\times$ 18 mm $\times$ 6 mm. The samples were cut from the processed sheet into the standard dimensions of 50.8 mm $\times$ 12.7 mm $\times$ 1.0 mm using a diamond saw. These dimensions are recommended by ASTM D 790 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, which provides for alternative test specimen sizes for materials that are $<$1.6-mm thick.[12] This ASTM standard was used instead of American National Standards Institute/American Dental Association Standard No. 139, Dental Base polymers, because the sheets used to prepare the specimens were less than the standard thickness specified in Standard No. 139.[13]

Eighty specimens of the prepared material were divided randomly into eight groups (with 10 specimens in each of the cleaning solutions and the toothbrushing group). For all groups, five of the specimens were tested for flexural modulus, and the other five were tested for light transmittance and surface roughness. One specimen from each cleaning group was randomly selected from the specimens used for light transmittance and surface roughness tests for scanning electron microscope (SEM) analysis. Each specimen was labeled to designate material, number, and cleaning method.

Twice each week for 6 months, specimens were either immersed in 600 mL of the designated cleaning solution or brushed with a toothbrushing machine. The cleaning solutions were prepared according to the manufacturers' instructions. Specimens were wrapped in 100% cotton cheesecloth, with the specimens separated from one another by glass beads, suspended from a glass rod atop a beaker filled with the appropriate solution for a period of 15 minutes, with the exception of Polident which was used for 3 minutes per manufacturers' recommendation, and the solutions were stirred on a magnetic stir plate (Figure 1).

For the toothbrushing method, specimens were brushed with a custom-fabricated toothbrushing ma-

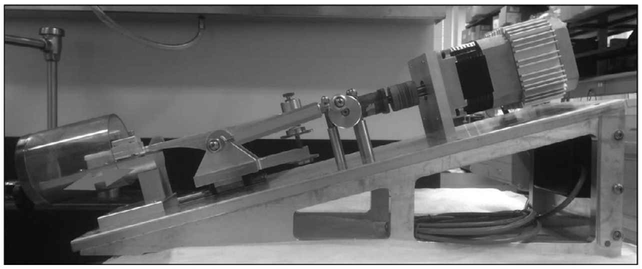

Figure 2. Standardized toothbrushing machine. The arrow represents the direction of brushing strokes.

chine (Figure 2) using double-distilled water for 2 minutes, twice weekly for 6 months as for the cleaning solutions. The speed control on the toothbrushing machine was set at 300 strokes/min (15% on controller), and the load was set at 50 g. Specimens were brushed parallel to the long axis (Figure 2, arrow). Following the sessions of cleaning, specimens were kept in a fresh batch of artificial saliva[14] at 37°C.

Light transmittance was determined according to a method published for measuring translucency of dental ceramics.[15] This method quantified the percent of light transmittance through the retainer material into a spectrometer/integrating sphere system consisting of the following components: a miniature spectrometer (Flame-S-VIS-NIR, Ocean Optics, Largo, Fla), a tungsten halogen lamp (Nikon MK II illuminator, Tokyo, Japan) with a flexible light guide (0.25″ × 0.312″ × 72″, Dolan-Jenner, Boxborough, Mass), integrating sphere (Labsphere, North Sutton, NH), fiber optic cable (QP100-2-UV-VIS, Ocean Optics), and a custom-designed specimen holder (Figure 3). During the procedure, a light energy reading was taken with the tungsten halogen light source connected to the spectrometer/integrating sphere system through a custom-fabricated specimen holder attached to a port in the integrating sphere. Next, the specimen was positioned in the holder in the path of the light source and the light energy reading was collected again, with the light transmitted through the specimen this time. From the two light energy measurements, the percent of light transmittance through the specimen was

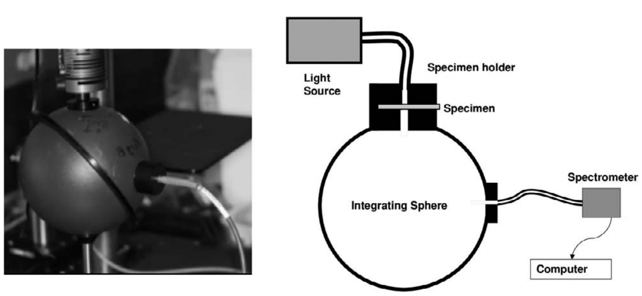

Figure 3. Light transmittance measurement system and its diagram.

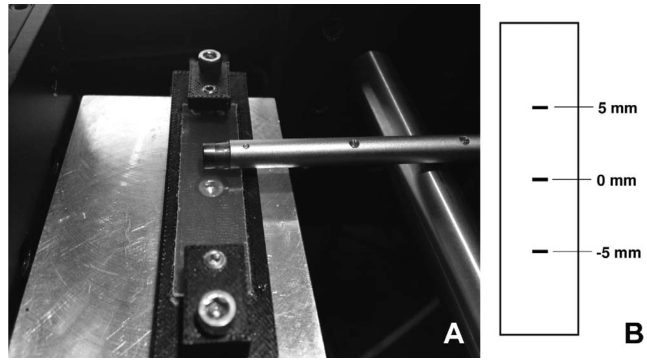

Figure 4. (A) Photo showing profilometer stylus and specimen holder. (B) Diagram showing specimen measurement locations.

calculated for wavelengths between 380 nm and 740 nm (Oceanview software, version 1.5, Ocean Optics).

Surface roughness was measured using a Surtronic 3+ profilometer (Taylor Hobson, Leicester, United Kingdom) placed on a Thorlabs motorized X-Y-Z stage controlled by Thorlabs APT software (Thorlabs, Newton, NJ), as shown in Figure 4A. The resolution of the measurements was set to 0.02 μm with the other profilometer settings as follows: 2.5 mm traverse length, cut-off value of 0.25 mm, and traverse speed of 1 mm/s. Surface roughness values were measured at three locations centered across the center of the specimen (Figure 4B). The resulting output was electronically transferred to the HyperTerminal application for Microsoft Windows XP (Hilgraeve, Monroe, Mich).

A mechanical testing machine (Instron 5582, Norwood, Mass) was used to conduct three-point bend testing of the specimens to measure flexural modulus. Using the calibrated mechanical test machine, each specimen was loaded at a cross-head speed of 1 mm/min. The specimen was loaded in the linear-elastic region of its stress/strain curve below the yield strength of the material. Pilot testing was performed to determine the ultimate flexural strength of the Essix ACE specimens, and then the specimens were loaded to approximately half of the mean ultimate flexural strength of the specimens in the pilot tests. The data were collected and processed using a custom-program in Testworks (MTS Systems, Eden Prairie, Minn).

The JCM-6000 Neoscope II Benchtop Scanning Electron Microscope (JEOL, Tokyo, Japan) was used to obtain qualitative SEM images to supplement the quantitative findings of the three previously described tests. SEM images at baseline and the end of the 6-month period were compared. The specimens were gold plated and images were collected at 10 kV, and 500× magnifications.

Table 1. Descriptive Statistics (%) and Pairwise (*P* Values) Mean Differences of Light Transmittance From Baseline to 6 Months Among the Cleaning Methods

Cleaning Method	Mean ± SD	Invisalign Cleaning Crystals	Retainer Brite	Polident	Listerine	2.5% Vinegar	0.6% Sodium Hypochlorite	3% Hydrogen Peroxide	Toothbrushing
Invisalign cleaning crystals	–2.96 ± 1.64	–	1.000	1.000	<0.001*	1.000	1.000	1.000	0.890
Retainer Brite	–2.78 ± 1.41	1.000	–	1.000	<0.001*	1.000	1.000	1.000	0.530
Polident	–3.48 ± 1.19	1.000	1.000	–	0.001*	1.000	1.000	1.000	1.000
Listerine	–7.38 ± 1.54	<0.001*	<0.001*	0.001*	–	<0.001*	<0.001*	<0.001*	0.061
2.5% vinegar	–2.10 ± 1.28	1.000	1.000	1.000	<0.001*	–	1.000	1.000	0.061
0.6% sodium hypochlorite	–2.76 ± 0.84	1.000	1.000	1.000	<0.001*	1.000	–	1.000	0.499
3% hydrogen peroxide	–2.71 ± 0.84	1.000	1.000	1.000	<0.001*	1.000	1.000	–	0.443
Toothbrushing	–4.74 ± 1.98	0.890	0.530	1.000	0.061	0.061	0.499	0.443	–

* Statistically significant at .05.

Statistical Analysis

Analysis of variance and Bonferroni test for multiple comparison were performed for the mean differences among cleaning methods. Student's *t*-test was used for comparison of variables between baseline and 6 months. Data analyses (SPSS statistics V.22.0, IBM Corp, Armonk, NY) were performed and statistical significance was set at .05.

RESULTS

At baseline, there was no mean significant difference of the tested properties among the specimens ($P >$ .05). Comparison of mean difference between from baseline to 6 months of each property among cleaning methods showed a statistically significant mean difference in light transmittance $F(7,32) = 9.282$ and flexural modulus $F(7,32) = 6.656$; $P <$ .001 among the cleaning methods. Multiple comparison tests indicated that specimens in Listerine had the greatest decrease in light transmittance compared with the other methods ($P <$ .001) except toothbrushing (Table 1). Specimens in hydrogen peroxide exhibited the most flexural modulus change and showed a significant mean difference compared with the ones in Invisalign Cleaning Crystal and Retainer Brite groups ($P <$ .001) (Table 2). There were no statistically significant mean differences among the cleaning methods for surface roughness [$F(7,32) = 0.963$; $P =$ .474].

Student's *t*-test indicated a consistent loss of light transmittance in the copolyester specimens when immersed in all cleaning methods at the 6-month time point compared with baseline (Figure 5). All methods produced similar roughness values when baseline and 6-month values were compared except for specimens cleaned in Listerine (Figure 6A). However, qualitative analysis with the SEM of specimens cleaned in Listerine showed no appreciable difference in surface texture when comparing micrographs at 500× magnification between baseline (Figure 6B) and 6 months (Figure 6C). There were significant flexural modulus increases when comparing baseline and 6-month values in all methods except for specimens cleaned with Invisalign Cleaning Crystal and Retainer Brite methods (Figure 7).

DISCUSSION

Essix ACE, made from copolyester, is considered esthetically pleasing because the material is virtually transparent while being durable when exposed to chemicals.[8] Copolyester is generated by modifications of polyester such as polyethylene terephthalate with

Table 2. Descriptive Statistics (MPa) and Pairwise (*P* Values) Mean Differences of Flexural Modulus From Baseline to 6 Months Among the Cleaning Methods

Cleaning Method	Mean ± SD	Invisalign Cleaning Crystals	Retainer Brite	Polident	Listerine	2.5% Vinegar	0.6% Sodium Hypochlorite	3% Hydrogen Peroxide	Toothbrushing
Invisalign cleaning crystals	99.20 ± 98.11	–	1.000	0.301	0.124	0.274	0.056	<0.001*	0.001*
Retainer Brite	149.80 ± 51.56	1.000	–	1.000	1.000	1.000	1.000	0.004*	0.066
Polident	183.60 ± 8.14	0.301	1.000	–	1.000	1.000	1.000	0.089	0.939
Listerine	194.60 ± 58.14	0.124	1.000	1.000	–	1.000	1.000	0.219	1.000
2.5% vinegar	184.80 ± 32.34	0.274	1.000	1.000	1.000	–	1.000	0.098	1.000
0.6% sodium hypochlorite	204.00 ± 26.84	0.056	1.000	1.000	1.000	1.000	–	0.457	1.000
3% hydrogen peroxide	283.00 ± 38.55	<0.001*	0.004*	0.089	0.219	0.098	0.457	–	1.000
Toothbrushing	252.80 ± 20.73	0.001*	0.066	0.939	1.000	1.000	1.000	1.000	–

* Statistically significant at .05.

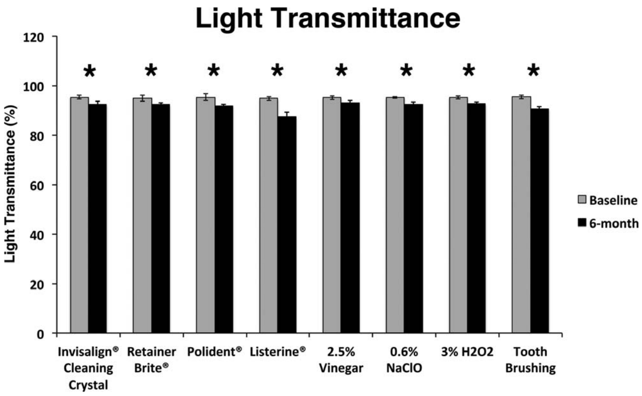

Figure 5. A bar graph of copolyester light transmittance between baseline and 6 months (*$P < .05$).

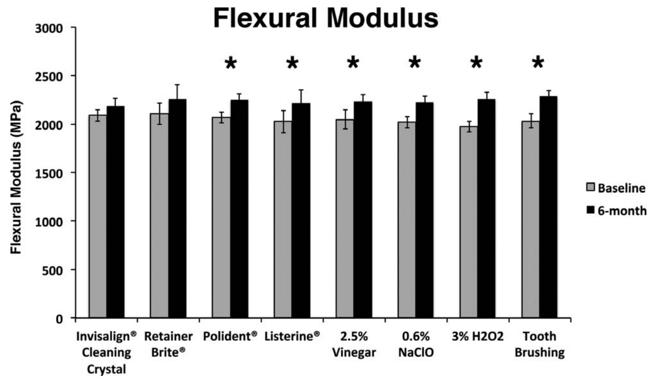

Figure 7. A bar graph of copolyester flexural modulus between baseline and 6 months (*$P < .05$).

isophthalic acid or other diols. Compared to polypropylene polymers, copolyester has been reported to be more transparent and wear less.[7,16] In the present study, the long-term physical property changes of this copolyester material were evaluated after exposure to different cleaning methods, which have been suggested to patients by orthodontists without any long-term evidence. Previous researchers demonstrated that long-term intraoral exposure accelerated changes in surface morphology, tensile strength, and elastic modulus of vacuum-formed retainer material (polyethylent- erephthalat-glycolmodified ethylen-1,4-cycloexylen dimethy- lenterephthalat copolymer).[17]

In this study on the use of different cleaning methods, copolyester samples in all groups stored in

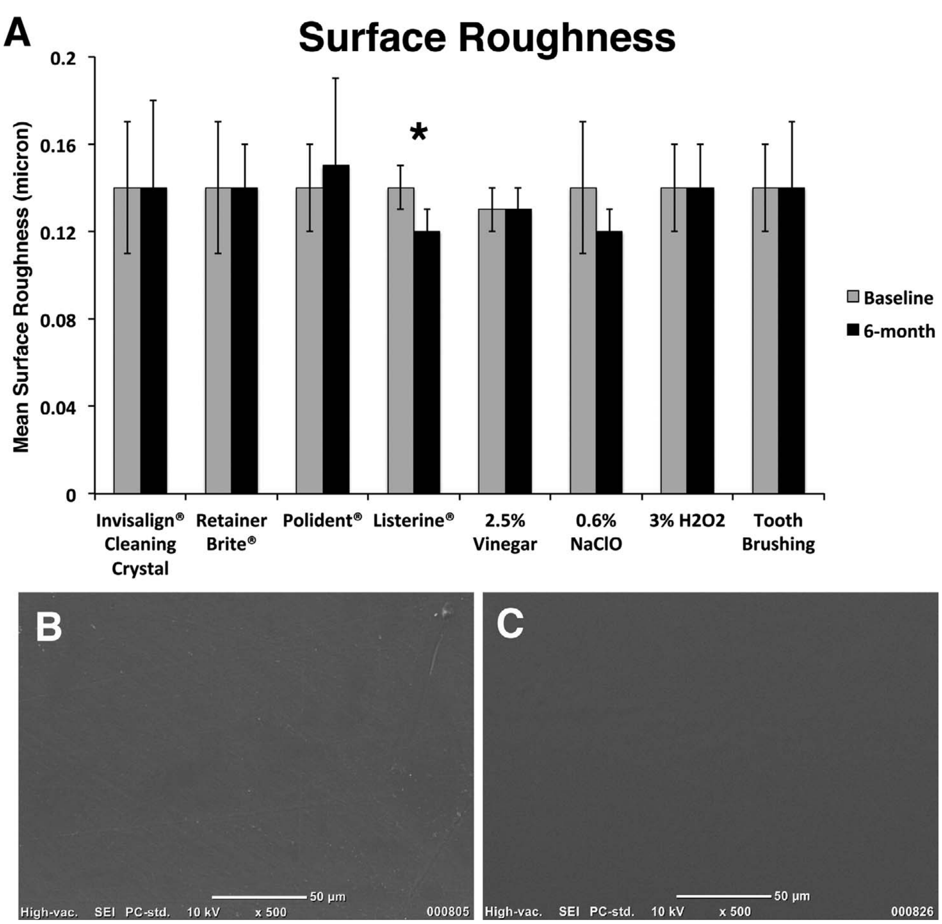

Figure 6. (A) A bar graph of copolyester surface roughness between baseline and 6 months (*$P < .05$) and scanning electron microscope images (17 kV 500 X) of copolyester specimens from the Listerine group at (B) baseline and (C) 6 -months.

artificial saliva at 37°C between cleaning interventions demonstrated aging changes of a decrease of translucency and flexibility over time. The degree to which translucency and flexibility decreased varied among the cleaning methods. Generally, copolyester polymer has exhibited resistance to chemicals such as ethyl alcohol, acetic acid, NaOCl, and hydrogen peroxide very well but it can be discolored by ethyl alcohol.[18] In this study, Listerine appeared to affect long-term translucency, roughness, and flexural modulus of Essix ACE material and affected the long-term translucency more than other cleaning methods. Since Listerine contains more than 50% water, approximately 21.6% ethanol, and traces of essential oil, such as eucalypthol and menthol, it is possible that the ethyl alcohol might have affected the properties of this copolyester material.[18]

Listerine caused the most notable surface roughness change; however, the surface roughness values were well below 0.5 micrometers, as measured by the profilometer. A report about the scale of perception of roughness by human tongues demonstrated that roughness could not be detected at a scale smaller than 0.5 μm.[19]

H_2O_2 appeared to affect the most long-term flexural change followed by the toothbrushing method. H_2O_2 is an oxidizing agent, which could produce free oxygen radicals leading to oxidation of the polymer. Oxidation is a chemical reaction that occurs with aging of some polymers, such as polyethylene or polypropylene.[20] The oxidation from the oxygen radical of H_2O_2 might interfere with the long-term properties of this copolyester material; however, more experiments are needed to confirm this speculation. In addition, a limited number of literature showed that cyclic loading could alter the oxidative stability of polyethylene and may assist in the progression of oxidation.[21] Therefore, toothbrushing, which introduced a slight mechanical loading force on the material, may have altered the flexibility of the copolyester material. For polyurethane material, it has been shown that toothbrushing also altered the long-term flexibility of the material.[11] This study was the first to compare the long-term effects on the physical properties of copolyester retainer material after long-term exposure to different cleaning methods.

A limitation of this study was that the specimens used were flat and did not reflect the real shape of thermoplastic retainers. However, for the purpose of this study, flat standard specimens with uniform cross-sectional areas were necessary for the flexural modulus and light transmittance measurements, and they provided standard results that can be used in future studies. Though the specimens were flat, they were processed (heat-vacuum formed) similarly to orthodontic retainers, which eliminated the processing step as a variable in the study.

CONCLUSIONS

- The results suggest that different cleaning methods affect the long-term physical properties of copolyester retainer material.
- Listerine and H_2O_2 are not recommended as cleaning solutions for copolyester retainer material.
- At the present time, no cleaning method for copolyester retainer material is ideal.

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