Original Article

Long-term effects of various cleaning methods on polypropylene/ethylene copolymer retainer material

Emily Wible[a]; Manika Agarwal[a]; Sibel Altun[a]; Tyler Ramir[a]; Grace Viana[b]; Carla Evans[c]; Henry Lukic[d]; Spiro Megremis[e]; Phimon Atsawasuwan[f]

ABSTRACT

Objectives: To evaluate long-term light transmittance, surface roughness, and flexural modulus of polypropylene/ethylene copolymer retainer material after exposure to different cleaning methods.

Materials and Methods: Standardized polypropylene/ethylene copolymer retainer specimens ($n = 70$, 50.8 mm $\times$ 12.7 mm $\times$ 1.0 mm) were subjected to seven chemical cleaning solutions: Invisalign cleaning crystals, Retainer Brite, Polident, Listerine mouthwash, 2.5% acetic acid, 0.6% NaClO, and 3% H_2O_2 for 6 months. The specimens were exposed to the different solutions twice a week for 15 minutes or according to manufacturer's instructions, then stored in artificial saliva at 37°C. Another group of specimens ($n = 10$) were 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 analysis was performed using a scanning electron microscope (SEM). Statistical analyses were performed at a significance level of .05.

Results: The results showed that light transmittance decreased significantly from baseline for all cleaning methods at 6 months. For an individual method, no significant differences were observed between specimens at baseline and 6 months in surface roughness and flexural modulus. No discernible differences in surface features were observed on SEM images.

Conclusions: The results indicate that different cleaning methods affect the long-term light transmittance of the studied polypropylene/ethylene copolymer retainer material. However, for an individual cleaning method, no significant differences were shown for surface roughness or flexural modulus values at 6-months compared to baseline. (*Angle Orthod.* 2019;89:432–437.)

KEY WORDS: EssixC+; Thermoplastic retainer; Retainer cleaning; Polypropylene/ethylene copolymer; Translucency

[a] Postgraduate Student, Department of Orthodontics, University of Illinois at Chicago, Chicago, Ill, USA.

[b] Statistician, Department of Orthodontics, University of Illinois at Chicago, Chicago, Ill, USA.

[c] Clinical Professor, Department of Orthodontics and Dentofacial Orthopedics, Boston University, Boston, Mass, USA.

[d] Engineer Research Associate, Research and Standards Department of the Sciences Institute of the American Dental Association, Chicago, Ill, USA.

[e] Director, Research and Standards Department of the Sciences Institute of the American Dental Association, Chicago, Ill, USA.

[f] Associate Professor, Department of Orthodontics, University of Illinois at Chicago, Chicago, Ill, USA.

Corresponding author: Dr Phimon Atsawasuwan, Associate Professor, Department of Orthodontics, University of Illinois at Chicago, Chicago, IL 60612, USA
(e-mail: patsawas@uic.edu)

Accepted: October 2018. Submitted: June 2018.
Published Online: January 2, 2019

INTRODUCTION

Following the completion of orthodontic treatment, one of the most important goals is maintaining the finished result. It was reported that approximately 70% of orthodontic cases result in some degree of relapse.[1] The causes of relapse are due to a number of different factors, including the periodontium, occlusion, soft tissue, and growth.[2,3] Various removable and fixed retainer appliances are implemented to maintain the finished orthodontic result. Some examples of retention appliances include traditional Hawley retainers, spring aligners, and fixed lingual retainers.[4] Clear thermoplastic retainers have increased in popularity due to their desired esthetics and ease of fabrication.[5] When compared to the traditional Hawley retainers, clear thermoplastic retainers have been found to be equally effective in retention following orthodontic treatment.[6]

The two most common materials used for vacuum-formed retainers (VFRs) are polyethylene polymers and polypropylene/ethylene copolymers. Polyethylene polymers are considered more esthetic because the material is virtually transparent; however, polypropylene/ethylene copolymers are considered to be more durable and flexible.[7] A study showed that environmental conditions such as temperature, humidity, and pressure influence the mechanical behaviors of various clear thermoplastic products.[8] Several studies have focused on work of fracture,[9] wear resistance,[10] and discoloration[11] of various clear thermoplastic retainer products. Despite the increase in popularity of clear thermoplastic retainers, research regarding this desirable retention appliance has remained relatively limited. Recently, results were reported on the effects of different cleaning methods on polyurethane and copolyester retainer materials. Different retainer materials required different cleaning solutions to maintain their original translucency and flexibility.[12,13] Based on the experimental design, Invisalign cleaning crystals, Polident, and Listerine can be used for cleaning polyurethane retainer material twice a week; however, toothbrushing and diluted vinegar were not recommended.[12] For copolyester retainer material, Invisalign cleaning crystals and Retainer Brite can be used for cleaning twice a week; however, tooth brushing and Listerine were not recommended.[13] Due to the long-term use of retainers following orthodontic treatment, it is imperative to maintain the original function of the clear thermoplastic products for an extended time. The aim of this study was to evaluate the long-term effect of eight different cleaning methods on light transmittance, surface roughness, and flexural modulus of a polypropylene/ethylene copolymer retainer material (Essix C+, Dentsply GAC, York, Pa) over a 6-month period.

MATERIALS AND METHODS

Polypropylene/ethylene copolymer retainer material (Essix C+) was first heated and vacuumed over a stainless steel block with the dimensions of 55 mm $\times$ 18 mm $\times$ 6 mm. Specimens were then cut from the processed sheets 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 less than 1.6 mm thick.[14] This ASTM standard was used instead of ANSI/ADA 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.[15]

Eighty specimens of the prepared material were divided randomly into eight groups (with 10 specimens in each of the cleaning solution and toothbrushing groups). The eight different cleaning methods evaluated were: Invisalign Cleaning Crystals (Align Technology, Inc.; San Jose, Calif); Retainer Brite Cleaning Tablets (Dentsply International; York, Pa); Polident Antibacterial Denture Cleaner (GlaxoSmithKline; Philadelphia, Pa); Listerine Cool Mint (Johnson & Johnson Consumer, Inc.; New Brunswick, NJ); 2.5% vinegar; 0.5% sodium hypochlorite; 3% hydrogen peroxide; and toothbrushing with distilled water. For all eight cleaning methods, five of the 10 specimens were subjected to tests for flexural modulus, and the other five specimens were subjected to tests 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 a scanning electron microscope (SEM) analysis. Each specimen was labeled to designate material, number, and cleaning method.

Twice a week, specimens were either immersed in 600 mL of their designated cleaning solution or brushed with a toothbrushing machine. The cleaning solutions were prepared according to the manufacturers' instructions. When the specimens were immersed in their designated solutions, the following procedure was used: Specimens were wrapped in 100% cotton cheesecloth with the specimens separated from one another by glass beads; the cheesecloths were suspended from glass rods atop beakers filled with one of the designated seven solutions for 15 minutes (the exception was 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 machine (Figure 2) using double-distilled water for 2 minutes, twice weekly, over the same 6 months as the cleaning solutions. The speed control on the toothbrushing machine was set at 300 strokes/min (15% on the controller), and the load was set at 50 g. Specimens were brushed parallel to their long axis (Figure 2, arrow). Following the sessions of cleaning, specimens were kept in a fresh batch of artificial saliva[16] at 37°C.

Light transmittance was determined according to a method published for measuring translucency of dental ceramics.[17] This method quantified the percent 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, Seminole, Fla); a tungsten halogen lamp (Nikon MK II illuminator, Tokyo,

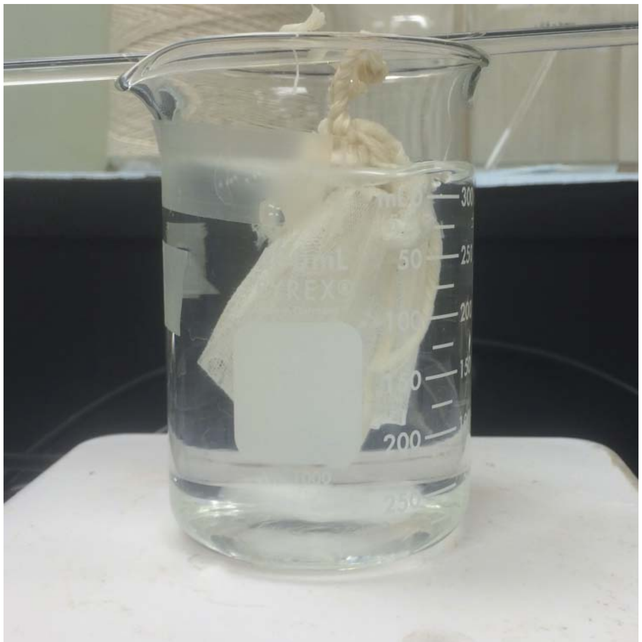

Figure 1. Specimens submerged in a cleaning solution on a magnetic stir plate.

Japan) with a flexible light guide (0.25 × 0.312 × 72 inches, Dolan-Jenner, Boxborough, Mass); an integrating sphere (Labsphere, North Sutton, NH); a 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 taken with the light transmitted through the specimen. From the two light energy measurements, the percent of light transmittance through the specimen was 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, UK) placed

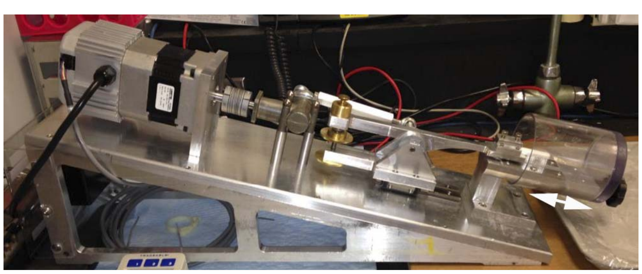

Figure 2. Standardized toothbrushing machine. The arrow represents the direction of brushing stroke.

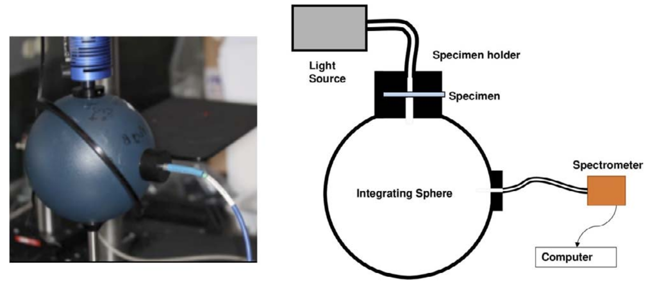

Figure 3. Diagram of light transmission measurement system.

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 device 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 each 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, MA) 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. Each 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 C+ material, and then the specimens were loaded to approximately half of the mean ultimate flexural strength determined from 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

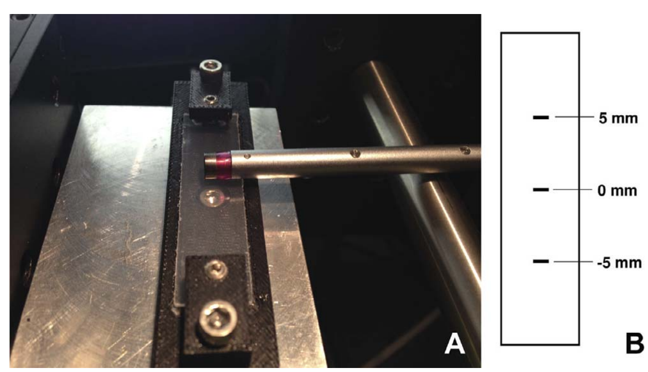

Figure 4. (A) Photo showing profilometer stylus and specimen holder. (B) Diagram showing specimen measurement locations.

Table 1. Descriptive Statistics (%) and Pair-wise (P Values) Mean Differences of Surface Roughness From Baseline to 6 Months Among the Cleaning Methods

Cleaning Methods	Mean ± SE	Invisalign Cleaning Crystals	Retainer Brite	Polident	Listerine	2.5% Vinegar	0.6% Sodium Hypochlorite	3% Hydrogen Peroxide	Toothbrushing
Invisalign Cleaning Crystals	−0.01 ± 0.03	-	1.000	1.000	1.000	1.000	0.561	1.000	1.000
Retainer Brite	−0.04 ± 0.02	1.000	-	1.000	0.561	0.191	0.013*	1.000	0.330
Polident	−0.01 ± 0.01	1.000	1.000	1.000	1.000	1.000	0.930	1.000	1.000
Listerine	0.01 ± 0.03	1.000	0.561	1.000	-	1.000	1.000	1.000	1.000
2.5% Vinegar	0.02 ± 0.01	1.000	0.191	1.000	1.000	-	1.000	1.000	1.000
0.6% Sodium Hypochlorite	0.04 ± 0.03	0.561	0.013*	0.930	1.000	1.000	-	0.252	1.000
3% Hydrogen Peroxide	−0.01 ± 0.04	1.000	1.000	1.000	1.000	1.000	0.252	-	1.000
Toothbrushing	0.02 ± 0.01	1.000	0.330	1.000	1.000	1.000	1.000	1.000	-

*$P < 0.05$

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 500X magnification.

Statistical Analysis

Analysis of variance (ANOVA) and Bonferroni test for multiple comparisons 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 0.05.

RESULTS

At baseline, there was no mean significant difference of the tested variables among the specimens ($P > .05$). Comparison of mean differences from baseline to 6 months of each variable for all the different cleaning methods showed statistically significant mean differences in both surface roughness: $F(7, 32) = 2.926$, P value $< .05$; and flexural modulus: $F(7, 32) = 2.829$, P value $< .05$, values among the cleaning methods. Multiple comparisons indicated that the specimens cleaned with Retainer Brite exhibited the largest surface roughness change, which was significantly different compared to the specimens cleaned with the 0.6% sodium hypochlorite ($P < .01$) (Table 1). However, qualitative analysis of the SEM images of the specimens cleaned with Retainer Brite (Figure 5B) compared to the images of the specimens cleaned with the 0.6% sodium hypochlorite solution (Figure 5C) at 500× magnification exhibited no appreciable differences in the surface features at 6-months and baseline (Figure 5A). The multiple comparisons showed that specimens cleaned with 3% hydrogen peroxide exhibited the greatest change in flexural modulus, which was significantly different compared to the specimens cleaned with Listerine ($P < .05$) (Table 2). There were no statistically significant mean differences among the cleaning methods for light transmittance, $F(7, 32) = 0.601$, P value $= .750$.

The Student's *t*-test indicated a consistent decrease in light transmittance through the polypropylene/ethylene copolymer specimens for all cleaning methods at 6 months compared to baseline (Figure 6). All cleaning methods produced similar surface roughness and

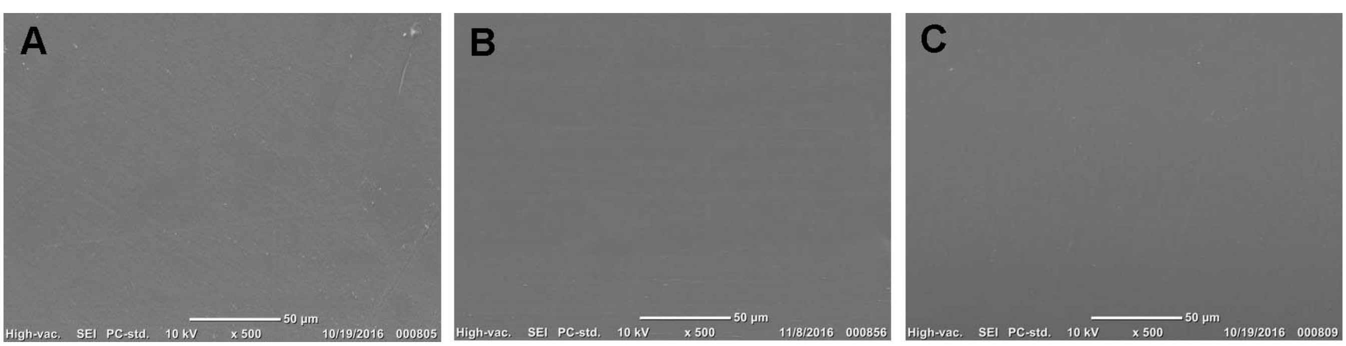

Figure 5. SEM images of copolymer specimens from (A) baseline, (B) 6 months after Retainer Brite and (C) 6 months after 0.6% sodium hypochlorite.

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

Cleaning Methods	Mean ± SE	Invisalign Cleaning Crystals	Retainer Brite	Polident	Listerine	2.5% Vinegar	0.6% Sodium Hypochlorite	3% Hydrogen Peroxide	Toothbrushing
Invisalign Cleaning Crystals	−18.37 ± 30.64	-	1.000	1.000	0.618	1.000	1.000	1.000	1.000
Retainer Brite	−35.09 ± 24.41	1.000	-	1.000	0.101	1.000	1.000	1.000	1.000
Polident	−22.60 ± 60.07	1.000	1.000	-	0.397	1.000	1.000	0.089	0.939
Listerine	34.82 ± 27.24	0.618	0.101	0.397	-	1.000	0.580	0.007*	1.000
2.5% Vinegar	−8.99 ± 30.95	1.000	1.000	1.000	1.000	-	1.000	1.000	1.000
0.6% Sodium Hypochlorite	−19.03 ± 26.57	1.000	1.000	1.000	0.580	1.000	-	1.000	1.000
3% Hydrogen Peroxide	−56.67 ± 22.23	1.000	1.000	1.000	0.007*	1.000	1.000	-	0.568
Toothbrushing	−2.20 ± 19.23	1.000	1.000	1.000	1.000	1.000	1.000	0.568	-

$^*P < 0.05$

flexural modulus values at 6 months compared to baseline.

DISCUSSION

Essix C+, made from a polypropylene/ethylene copolymer, is a desirable material for thermoplastic retainers due to its translucent and durable nature.[7] Despite its esthetic advantage, research has been limited on evaluating the effect of cleaning methods on the function of the material. In addition, it seems that different thermoplastic materials behaved differently once exposed to different cleaning solutions.[12,13] The present study evaluated the long-term effects of various cleaning methods, which have been suggested to patients by orthodontists for use with Essix C+ without good information on the long-term effects on the behavior of the material.

In this study, mean differences between 6 months and baseline indicated that Retainer Brite showed the most change in surface roughness. However, the surface roughness values were well below 0.5 μm as measured by the surface profilometer. The implication is that the significant roughness change might not be clinically significant. For instance, a report about the scale of perception of roughness by human tongues demonstrated that human tongues could not detect roughness at a scale smaller than 0.5 μm.[18] Given that the magnitude of surface roughness values measured in the present study were less than 0.5 μm, it could be reasoned that this statistical difference in surface roughness is not clinically relevant.

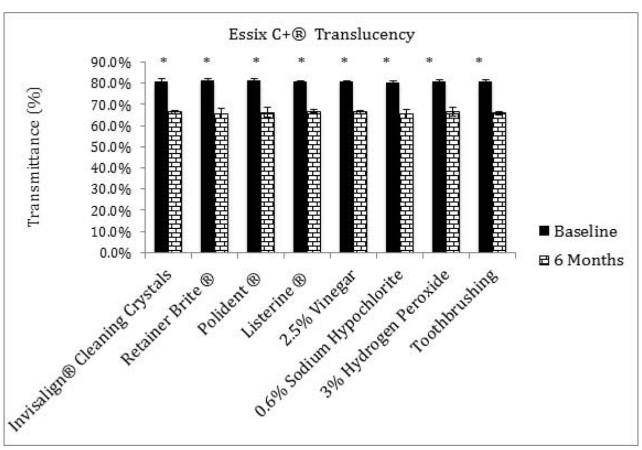

Figure 6. A bar graph of copolymer light transmittance between baseline and 6 months ($^*P < .05$).

The mean differences between specimens values at 6 months and baseline indicated that the 3% hydrogen peroxide resulted in the greatest difference in flexural modulus. As listed on the MSDS sheet for Essix C+, the material is not compatible with oxidizing agents.[19] Therefore, this finding was not surprising given the powerful oxidizing abilities of hydrogen peroxide.[20] Polymer oxidation is known to result in an increase in stiffness (increase in flexural modulus).[21,22] Given Essix C+ incompatibility with oxidizing agents, the diluted 3% hydrogen peroxide is speculated to have acted as an oxidizing agent that led to the statistically significant change in flexural modulus value over the six month time period.

In this study of cleaning methods, polypropylene/ethylene copolymer specimens in all groups, stored in artificial saliva at 37°C between cleaning interventions, demonstrated aging appearance as a decrease in translucency over time. The degree of decrease in translucency of the specimens varied among the cleaning methods.

A limitation of this study was that the flat specimens did not mimic the clinical shape of thermoplastic retainers, which follow the contour of teeth. However, flat specimens were deemed necessary in this study to provide a uniform cross-sectional area to make standard flexural modulus and light transmittance measurements, which provided standard results that can be used in future studies. Although the specimens were flat, they were processed (heat-vacuum formed) in the same manner used to fabricate thermoplastic retainers, minimizing the effect of this limitation on the study.

CONCLUSIONS

- The results indicate that specific cleaning methods affect the long-term light transmittance of polypropylene/ethylene copolymer retainer material.
- H_2O_2 is not recommended as a cleaning solution for polypropylene/ethylene copolymer retainer material due to its powerful oxidizing abilities.
- At the present time, there is no ideal cleaning method for polypropylene/ethylene copolymer retainer material.

ACKNOWLEDGMENTS

Essix C+ material and Retainer Brite was kindly provided by GAC Dentsply Company. Listerine was kindly provided by Johnson and Johnson Consumer Company.

REFERENCES

1. Sadowsky C. Long term assessment of orthodontic relapse, *Am J Orthod Dentofacial Orthop*. 1982;82:456–463.
2. Littlewood SJ, Millett DT, Doubleday B, Bearn DR, Worthington HV. Orthodontic retention: a systematic review, *J Orthod*. 2006;33:205–212.
3. Melrose C, Millett DT. Toward a perspective on orthodontic retention? *Am J Orthod Dentofacial Orthop*. 1988;113:507–514.
4. Arvystas MG. Maintaining orthodontic success: retention for the adult patient. *J Esthet Dent*. 1996; 8(6):279–283.
5. Chang CS, Al-Awadi S, Ready D, Noar J. An assessment of the effectiveness of mechanical and chemical cleaning of Essix orthodontic retainer. *J Orthod*. 2014;41:110–117.
6. Kalha AS. Hawley or vacuum-formed retainers following orthodontic treatment. *Evid Based Dent*. 2014;15:110–111.
7. Sheridan JJ, LeDoux W, McMinn R. Essix retainers: fabrication and supervision for permanent retention. *J Clin Orthod*. 1993;27:37–45.
8. Ryokawa H, Miyazaki Y, Fujishima A, Miyazaki T, Maki K. The mechanical properties of dental thermoplastic materials in a simulated intraoral environment. *Orthod Waves*. 2006; 65:64–72.
9. Pascual AL, Beeman CS, Hicks EP, Bush HM, Mitchell RJ. The essential work of fracture of thermoplastic orthodontic retainer material. *Angle Orthod*. 2010;80:554–560.
10. Raja TA, Littlewood SJ, Munyombwe T, Bubb NL. Wear resistance of four types of vacuum-formed retainer materials: a laboratory study. *Angle Orthod*. 2014;84:656–664.
11. Zafeiriadis AA, Karamouzos A, Athanasiou AE, Eliades T, Palaghias G. In vitro spectrophotometric evaluation of Vivera® clear thermoplastic retainer discolouration, *Aust Orthod J*. 2014;30:192–200.
12. Agarwal M, Wible E, Ramir T, et al. Long-term effects of seven cleaning methods on light transmittance, surface roughness, and flexural modulus of polyurethane retainer material. *Angle Orthod*. 2018; 88:355–362.
13. Wible E, Agarwal M, Altun S, et al. Long-term effects of different cleaning methods on copolyester retainer properties. *Angle Orthod*. 2018 Aug 3. doi: 10.2319/010218-2.1.
14. ASTM International. *ASTM D790-17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*. West Conshohocken, PA; 2017.
15. ANSI/ADA Standard No. 139: 2012 “Dental Base Polymers.” Available at: www.ada.org. Accessed November 20, 2018.
16. Nakagawa M, Matsuya S, Shiraishi T, Ohta M. Effect of fluoride concentration and pH on corrosion behavior of titanium for dental use. *J Dent Res*. 1999;78:1568–1572.
17. Spink LS, Rungruanganut P, Megremis S, Kelly JR. Comparison of an absolute and surrogate measure of relative translucency in dental ceramics. *Dent Mater*. 2013; 29: 702–707.
18. Jones CS, Billington RW, Pearson GJ. The in vivo perception of roughness and restorations. *Br Dent J*. 2004; 196:42–45.
19. Essix C Plastics. MSDS No. 25-131-25, 25-134-78, 25- 135-00. Dentsply GAC, Bohemia, NY, April 13, 2007. Available at: http://www.dentalbiz.com.au/ESSIX-C-PLASTICS.pdf. Accessed November 20, 2018.
20. Hydrogen peroxide is a powerful oxidizer. USP Technologies, Atlanta, GA; 2016. Available at: http://www.h2o2.com/products-and-services/us-peroxide-technologies.aspx?pid=112. Accessed November 13, 2016.
21. Sepe M. Materials: The mystery of physical aging: Part 1. *Plastics Technology 2014*. https://www.ptonline.com/columns/the-mystery-of-physical-aging-part-1. 10/23/2014
22. Sastri VR. *Plastics in Medical Devices: Properties, Requirements and Applications*. 2nd ed. Atlanta, GA: William Andrew Publishing; 2013.