Original Article

An In Vitro Study Simulating Effects of Daily Diet and Patient Elastic Band Change Compliance on Orthodontic Latex Elastics

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Abstract: This project investigated the effects of food exposure and patient compliance with elastic-band change on the degradation of forces in 3/16–inch, medium-wall, latex elastic bands during a simulated day of clinical wear. Six levels of daily diet/patient compliance were chosen as representative of orthodontic patients and a quasicontrol group. The groups differed with respect to how much exposure to artificial saliva and foodstuffs they experienced. After exposure in mild tension to daily diets and based on compliance with instructions about changing orthodontic elastics, the elastics were tested in tensile mode by stretching to 25 mm, where the load was recorded in newtons. The bands of three manufacturers, Rocky Mountain Orthodontics (RMO), 3M Unitek (UNO), and American Orthodontics (AMO), were examined, with 10 bands per group, per manufacturer, forming a cohort. Two-way analysis of variance and the Tukey-Kramer honestly significant difference tests were used to identify statistical significance ($P > .05$). With respect to bands from a single manufacturer, no differences were found between daily diet/patient compliance levels. However, differences ($P < .0001$) were found between manufacturers' bands. RMO $>$ UNO $>$ AMO in all environments. Over a 24-hour period, latex elastics maintain their applied load in the simulated oral environments. (*Angle Orthod* 2004;74:234–239.)

Key Words: Degradation; Food; Exposure; Elastomer; Polymer

INTRODUCTION

Polymeric elastic bands provide one of the bases for orthodontic movement of teeth. Compared with heavy-force application, light-force application at the proper rates provides for rapid tooth movement with least patient discomfort and minimal mobility during orthodontic therapy.[1] Elastic bands provide forces of these magnitudes and can be used to provide forces to augment or supplement those provided by the archwire.

In the mouth, elastics experience constant force expression, with considerable force degradation through the first day of use,[2] most of it being in the first hour of use.[3] Lumen size influences force degradation, with smaller sizes needing to be renewed more often to maintain planned force application.[4] In attempts to mimic various oral environments, some studies have investigated the effects of simulated saliva environments,[5] pH,[6] and thermocycling[7] on force degradation. Various artificial salivas have been proposed, with the simplest formulation being 0.09% aqueous sodium chloride, commonly used in simulated intraoral environment studies.[8] Generally, the data demonstrated significant relaxation of force once elastics were exposed to experimental conditions.

Mechanical degradation effects are thought to be the primary cause for degradation of orthodontic elastic bands during clinical use.[3,4,7,9] However, leachable moieties have been isolated from some orthodontic elastic bands, and their increasing quantities in solution coincided with force degradation over time.[10] Although the degradation of orthodontic elastic materials has been studied, most of the experiments have been conducted in artificial saliva or air. Only the few aforementioned studies have assessed more aggressive environments, which simulated subplaque conditions and thermal challenges.

In contrast, the effects of food-simulating oral environments on dental polymeric restorative materials have been studied. Various forms of degradation of polymeric restorative materials have been found to be enhanced when the restorative materials are subjected to ethanol/water,[11,12] ethanol/artificial saliva,[13] lactic acid, citric acid, heptane, and alcohol/water[14] as simulated foods. Coffee, food dyes, vinegar, erythrosin,[15] whiskey, Coca-Cola®, and orange juice[16]

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TABLE 1. Commercially Procured Foods Used for Dietary Challenges

Product	Manufacturer	Main Composition
Reese's Puffs®	General Mills, Minneapolis, Minn	Sugar-sweetened corn/peanut cereal
Beefaroni®	ConAgra Foods, Omaha, Neb	Beef/pasta/tomato sauce
Chicken Fried Rice®	Luigino's, Inc, Duluth, Minn	Chicken/rice/vegetables/soy sauce
Milky Way®	M&M/Mars, Hakettstown, NJ	Chocolate/nougat/sugar
Pure Premium®	Tropicana, Bradenton, Fla	Pure, natural orange juice
Coca-Cola®	The Coca-Cola Co, Atlanta, Ga	Phosphoric acid, sugar, carbon dioxide, flavor
Vitamin D milk	Local dairies	Pasteurized whole milk

have been used directly to investigate degradation of restorative dental polymers by foods and food additives. Water is known to plasticize cross-linked polymers used intraorally, including latex rubber.[17,18] Additionally, other medical materials also have been studied. Plasticizers leaching from latex films, during physical aging, have demonstrated reduction in creep compliance, an indication of environmental degradation of latex rubber.[19] Similar information, applicable to orthodontic polymeric materials, would provide insight on the potential of these elastic materials to perform their function when left in place longer than recommended before changing to a fresh band.

Patients are routinely instructed to wear the elastic bands for 24 hours, except while eating/brushing teeth, replacing them after these actions. This would require at least one if not more band changes per day.[20] Patient compliance with instructions varies considerably, and noncompliance with instructions can range as high as 90%.[21] Failure to change elastic bands as recommended is commonly an area of noncompliance for orthodontic patients. Thus, some patients wear elastics the whole day before replacing them. During this period of wear, these patients consume foods, practice some forms of oral hygiene, and physically stress the bands, exposing them to thermal, chemical, and mechanical challenges, most of which have not been fully investigated with regard to their effects on the degradation of orthodontic polymers.

This study was designed and implemented to evaluate the effect of various food exposures and patient compliance levels in an artificial saliva environment during a 24-hour period on degradation of applied force in orthodontic elastics. Specific commercially available foodstuffs and food preparations were selected to simulate a daily diet, which might be typical for orthodontic patients.

MATERIALS AND METHODS

Determination of levels of daily dietary challenge and patient compliance

Observations of eating habits were made with regard to the type of foods eaten and the time required to consume them by one of the investigators. Meal and snack times were calculated by visually surveying more than 20 people (ages estimated between 12 and 35 years) with regard to time required to consume meals and eight ounces of liquid (soft drinks, juice, or milk). The people surveyed had no idea they were being observed because observation was carried out in various locations where food was served and consumed. Consumption of a full meal required a mean time of approximately 20 minutes, drinking a beverage took a mean time of approximately eight minutes, and eating a candy bar snack also took about eight minutes.

An artificial saliva, 0.09% aqueous sodium chloride solution, was prepared by dissolving reagent-grade granular sodium chloride in reverse osmosis (RO)–treated water having a resistance of 18 MΩ or greater.[9] This solution was maintained at a temperature of 37°C throughout the test period.

The foods that were selected for this study are listed in Table 1. These included a boxed cereal, a canned pasta/meat/tomato sauce meal, a microwave-ready meat/rice/vegetable meal, a chocolate/nougat candy bar, a cola-based soft drink, orange juice, and whole milk. All these items were purchased from the stock available at a local grocery store. The simulated breakfast was cereal in whole milk with orange juice. The simulated lunch was the pasta/meat/tomato sauce food combined with either milk or cola. The simulated dinner was the meat/rice/vegetable meal with either milk or cola. The candy bar was a between-meal snack. Colas also were used between meals for some diets. From these foods, several daily diets were derived.

Six levels of daily diet and band change compliance were derived using the food products listed above and compliance with typical professional instructions regarding changing of bands. These levels are described below.

A non–patient-simulating, quasicontrol group was selected for exposure of the elastic bands for 24 hours to the artificial saliva at 37°C, designated as group L1. For compliance with professional recommendations, an all-or-none position was chosen because this study involved a simulation of a single day. Therefore, a 12-hour exposure to artificial saliva was considered for a perfectly compliant patient who removed bands before eating the dinner meal and replaced them after brushing after dinner, but before retiring for the night, and then removed them before eating breakfast, designated as group L2. It was assumed that the groups L3–L6 did not comply with professional recommendations to change bands before eating and after brushing, but the group members wore the bands through the entire day with-

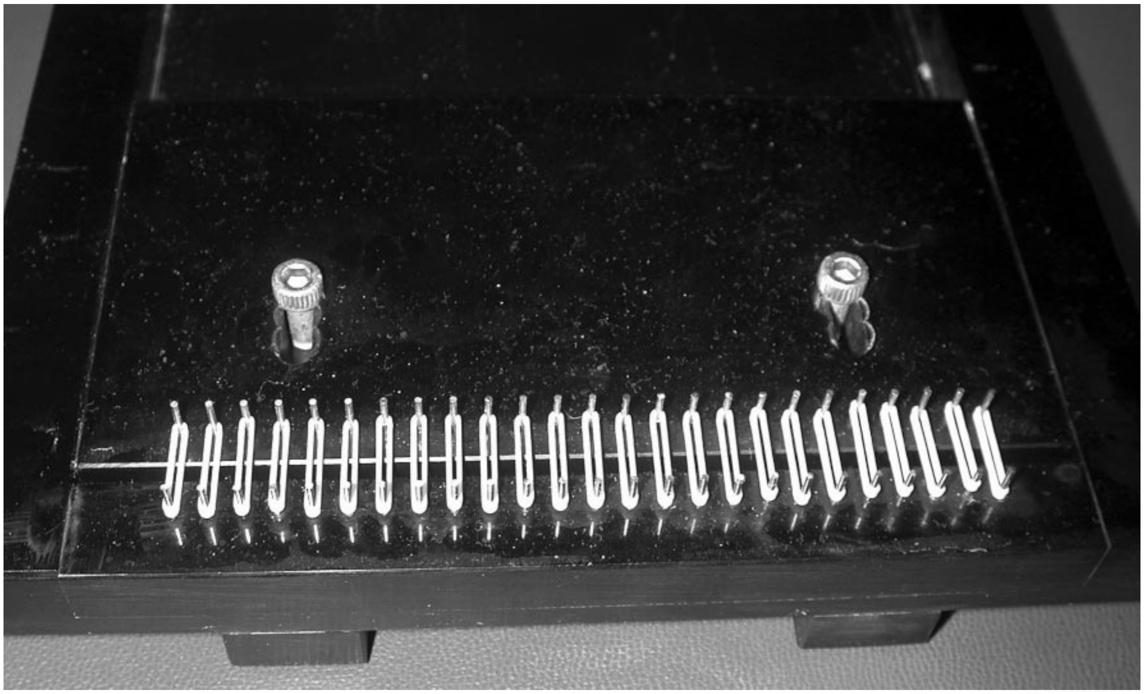

FIGURE 1. Orthodontic elastic bands stretched to 15 mm in the adjustable jig according to the experimental protocol.

TABLE 2. Identification of Experimental Groups According to Dietary Challenge and Patient Band Change Compliance Factors

Compliance Factors (Y = Yes, N = No) Daily Dietary Challenge and Band Change	Group					
	L1	L2	L3	L4	L5	L6
Patient band change compliance	N	Y	N	N	N	N
Breakfast: 15°C orange juice/milk/Reese's Puffs® slurry for 0.3 h	N	N	Y	Y	Y	Y
Lunch: 45°C Beefaroni®/saliva slurry for 0.3 h	N	N	Y	Y	Y	Y
Dinner: 45°C Chicken Fried Rice®/saliva slurry for 0.3 h	N	N	Y	Y	Y	Y
Milk drinks: 5°C, number of 0.1 h exposures/day	0	0	2	0	0	0
Cola drinks: 5°C, number of 0.1 h exposures/day	0	0	0	2	5	7
Snack: 25°C Milky Way®/saliva slurry, number of 0.1 h exposures/day	N	N	0	0	0	3
Total time exposed to foodstuff (h)	0	0	1.1	1.1	1.4	1.9
Total exposure time before elastic testing (h)	24	12	24	24	24	24

out changing them. These noncompliant groups differ only in the dietary challenges the elastic bands withstood. Thus, in this study, groups L2–L6 simulated patients, whereas group L1 did not.

Daily dietary challenge

Latex rubber orthodontic elastic bands were obtained from three manufacturers (3M Unitek, Monrovia, CA [UNO], American Orthodontics, Sheboygan, WI [AMO], and Rocky Mountain Orthodontics, Denver, CO [RMO]). All products were designated as having a 3/16–inch (about five mm) lumen diameter and were labeled by the company as ''medium wall,'' which measured about one mm in thickness and about 1.5 mm in width. For each group, from L1 to L6, 10 bands were exposed to the daily diets, forming a cohort. The elastics were selected randomly from the original packaging. Each cohort of 10 elastics was exposed to different daily diets.

All selected liquids and the chocolate bar snacks were given at eight-minute intervals. All simulated meals were given at 20-minute intervals. For the balance of the 24-hour test period, the elastics were immersed in an artificial saliva solution kept at a constant temperature of 37°C, except for group L1. Minimally, one hour of artificial saliva–exposure time passed between meal/snack/cola exposures.

Using a customized, adjustable jig, the elastics were stretched to 9/16 inch (~15 mm), which was three times their lumen sizes, to simulate the stress and strain of intraoral use,[4] as shown in Figure 1. Immediately after the elastics were installed in the jig, they were placed in the artificial saliva at 37°C for eight hours. With the exceptions of L1 and L2, the remaining cohorts were exposed to the sim-

TABLE 3. Results of the Two-Way analysis of variance (ANOVA) obtained from JMPIN

Source	DF	Sum of Squares	Mean Square	*F* Ratio	Probability > *F*
Whole Model					
Model	17	12.673196	0.745482	62.6595	<.0001
Error	162	1.927370	0.011897		
Total	169	14.600566			
Independent factor leverage					
Daily dietary challenge/patient compliance level					.4167
Manufacturer					<.0001
Daily dietary challenge/patient compliance level according to manufacturer					.0971

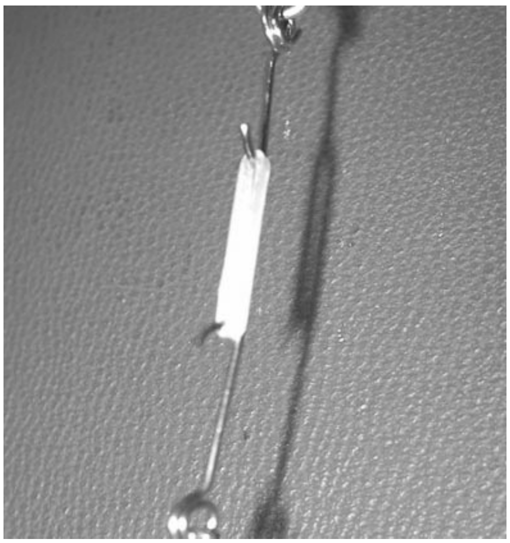

FIGURE 2. An orthodontic elastic band stretched to 25 mm in the custom-made testing jig designed for the Instron universal testing machine.

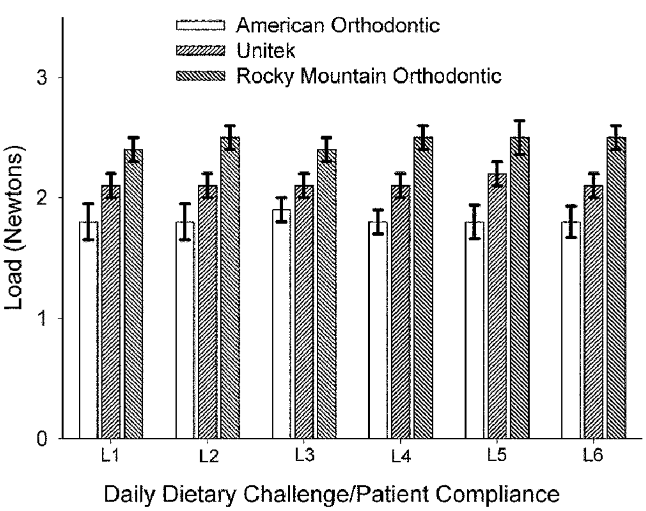

FIGURE 3. Load in newtons plotted vs daily dietary challenge/patient compliance. No differences were determined between daily dietary challenge/patient compliance levels for individual brands of elastic bands. However, significant differences were found between manufacturers' products ($P < .0001$).

ulated breakfast meal, as shown in Table 2. After the simulated breakfast meal exposure, the bands and jigs were rinsed with RO water at 37°C to remove any food debris and returned to artificial saliva storage until the next food challenge.

Subsequent food challenges were identical in procedure, where the bands were immersed in the food products for a specified time, as listed in Table 2, and rinsed before returning to artificial saliva. Meal and snack environments were created by crushing the foodstuffs into chosen liquids, as listed in Table 2. Baths were used to contain the different environments, and exposure was simply accomplished by moving the jig by hand from one environment to the other at designated intervals and for appropriate times of exposure.

All bands were tested after a 24-hour period of food exposure and/or storage, with the exception of L1, the ideal 12-hour case. Load measurements were performed using a universal testing machine (5500R, Instron Corp, Cambridge, Mass) under computer control. The elastic bands were held in a custom-made jig designed for tensile-mode testing. The cross-head of the universal testing machine stretched the elastics at 500 mm/minute until they reached three times their lumen size plus 10 mm, which measured a total of 25 mm.[4] At an extension of 25 mm, the cross-head was halted as programmed, and the load in newtons was immediately recorded. Figure 2 shows a band stretched to 25 mm in the custom-made jig used in these experiments.

For each cohort, mean loads and standard deviations were calculated. Using JMPIN (version 4.04, SAS Institute, Inc, Cary, NC), the data were analyzed statistically. A two-way analysis of variance (ANOVA) was used to find statistically relevant differences between band manufacturers and daily dietary challenge/patient compliance levels. The Tukey-Kramer honestly significant difference test was used to identify statistically different groups when ANOVA indicated a statistical difference in the model. The chosen level of confidence for all statistical calculations was 95% or $\alpha \leq .05$.

RESULTS

Figure 3 depicts the performance of these elastic bands with respect to daily dietary challenge. The two-way AN-

OVA found no significant differences between the daily dietary challenges, including the quasicontrol group. There were no significant interactions between independent factors; however, significant differences ($P < .0001$) were found between manufacturers' elastic bands. For all daily dietary challenge/patient compliance levels, the RMO bands were the strongest, the UNO bands were of intermediate strength, and the AMO bands were the lightest with respect to load at maximum experimental extension.

DISCUSSION

This study was undertaken to see what effect a day of exposure to oral conditions, typifying those found in a population of orthodontic patients, would have on orthodontic elastic bands when compared with a perfectly compliant patient and a quasicontrol experimental group. The purpose of the elastics is to provide a light yet directionally controlled force to move teeth in conjunction with arch wires, yet, in accordance with a predefined treatment plan to achieve an optimal result. With the daily dietary challenges and levels of patient compliance as determined by a preliminary study, all the latex elastics performed satisfactorily at each level during the simulated day.

The elastics were chosen on the basis of relevance, 3/16 of an inch is the size regularly used in orthodontic offices, and their small lumen size dictates more frequent changing.[4] The sample size of 10 for each environment is in accordance with previous studies.[22] The test times of 12 hours and 24 hours are shorter than in most previous studies. Because in clinical practice, orthodontists stress the changing of elastics at least everyday, if not more often, our time frame is clinically relevant.

In other studies, more severe test conditions, like longer exposures to varying environments of pH or temperature or testing the elastic bands to material failure, have shown more intense physical property degradation than the data presented here. However, these other studies expose the elastic bands to conditions beyond what they would normally endure in a single day of clinical use. Although the information gleaned from such studies may be important when investigating the material properties of these polymers, it may have no effect on the clinical performance of the bands themselves.

Because pH and thermocycling have been shown to affect the strength of orthodontic elastic bands in more aggressive in vitro tests than are shown herein, the length of time of exposure to chemical and thermal insults must be an important contributor to the reduction of physical properties. Under the present set of test conditions, which were selected to mimic a single day of exposure to actual foods and realistic thermal conditions approximating those encountered with meals, exposure to simulated saliva must reduce the overall effect of the insulting agents. Degradation of the latex rubber is likely to follow similar pathways as those presented in other studies, eg, mechanical and physical damage to the cross-linked polymer, solvent penetration of the latex by water and other liquid components of foods, and plasticizing by water or removal of plasticizers by dissolution from the polymer into the simulated oral environment.[3,4,7,9,10–19]

In this study, the RMO bands were the strongest, the UNO bands were next in strength, and the AMO bands were the least strong. Subnewton forces are known to effectively move teeth.[1] This may be clinically relevant because all these elastic bands apply forces over one N. A clinical study would be needed to determine clinical relevance. However, because all bands tested herein exceed one N in force, the bands would be qualitatively considered to apply medium forces and may not show clinical differences within their own group.

With respect to intra-arch elastics, this experiment was well designed because once applied in that manner, there should be little additional loading experienced during use. However, with respect to interarch elastic applications, a cyclic loading component might show variation in performance compared with our data, given that Chaconas et al[4] demonstrated that 24 hours of cyclic fatigue showed up to a 7% decrease in force. However, their cycling regimen exceeded what may actually occur during clinical use, and with only a maximum of 7% force reduction, this may be insignificant in clinical applications. A retrieval study to evaluate actual elastic bands, which are subjected to mechanical testing before and after clinical wear, might provide additional data for model validation.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

- At the various levels of simulated daily dietary challenge/patient compliance, these latex elastics maintain their applied force over a day of wear.
- Except for band breakage or recommended reasons of oral hygiene, beyond the once-per-day experience, there may be no need to change elastics during the day.
- The load ranking applied at an extension of 25 mm for 3/16–inch, medium-wall latex elastic bands is RMO > UNO > AMO for all daily dietary challenge/patient compliance levels.

REFERENCES

1. van Leeuwen EJ, Maltha JC, Kuijpers-Jagtman AM. Tooth movement with light continuous and discontinuous forces in beagle dogs. *Eur J Oral Sci.* 1999;107:468–474.
2. Bertran Von C. The forces of the rubber bands. [Die Kräfte der orthodontischen Gummiligatur.] *Fortschr Orthod.* 1931;1:605.
3. Kanchana P, Godfrey K. Calibration of force extension and force degradation characteristics of orthodontic latex elastics. *Am J Orthod Dentofacial Orthop.* 2000;118:280–287.

4. Chaconas SJ, Caputo AA, Belting CW. Force degradation of orthodontic elastics. *CDA J.* 1978;6:58–61.
5. Andreasen GF, Bishara SE. Comparison of time related forces between plastic alastiks and latex elastics. *Angle Orthod.* 1970; 40:319–328.
6. Ferriter JP, Meyer CE, Lorton L. The effects of hydrogen ion concentration on the force degradation rate of orthodontic polyurethane chain elastics. *Am J Orthod Dentofacial Orthop.* 1990; 98:404–410.
7. DeGenova DC, McInnes-Ledoux P, Weinberg R, Shaye R. Force degradation of orthodontic elastomeric chains—a product comparison study. *Am J Orthod.* 1985;87:377–384.
8. Stevenson JS, Kusy RP. Force application and decay characteristics of untreated and treated polyurethane elastomeric chains. *Angle Orthod.* 1994;64:455–464.
9. Huget EF, Patrick KS, Nunez LJ. Observations on the elastic behavior of a synthetic orthodontic elastomer. *J Dent Res.* 1990;69: 496–501.
10. Sun D, Monaghan P, Brantley WA, Johnston WM. Potentiodynamic polarization study of the in vitro corrosion behavior of 3 high-palladium alloys and a gold-palladium alloy in 5 media. *J Prosthet Dent.* 2002;87:86–93.
11. McKinney JE, Wu W. Chemical softening and wear of dental composites. *J Dent Res.* 1985;64:1326–1331.
12. Ferracane JL, Marker VA. Solvent degradation and reduced fracture toughness in aged composites. *J Dent Res.* 1992;71:13–19.
13. Lee SY, Greener EH, Mueller HJ. Effect of food and oral simulating fluids on structure of adhesive composite systems. *J Dent.* 1995;23:27–35.
14. Yap AU, Low JS, Ong LF. Effect of food-simulating liquids on surface characteristics of composite and polyacid-modified composite restoratives. *Oper Dent.* 2000;25:170–176.
15. Dietschi D, Campanile G, Holtz J, Meyer JM. Comparison of the color stability of ten new-generation composites: an in vitro study. *Dent Mater.* 1994;10:353–362.
16. Abu-Bakr N, Han L, Okamoto A, Iwaku M. Color stability of compomer after immersion in various media. *J Esthet Dent.* 2000; 12:258–263.
17. Bastioli C, Romano G, Migliaresi C. Water sorption and mechanical properties of dental composites. *Biomaterials.* 1990;11:219–223.
18. Guo JH, Robertson RE, Amidon GL. An investigation into the mechanical and transport properties of aqueous latex films: a new hypothesis for the film-forming mechanism of aqueous dispersion system. *Pharm Res.* 1993;10:405–410.
19. Rosen SL. *Fundamental Principles of Polymeric Materials.* 2nd ed. New York, NY: John Wiley & Sons; 1993:97–101.
20. Mitchell L. *An Introduction to Orthodontics.* 2nd ed. Oxford, UK: Oxford University Press; 2001:164.
21. Masek BJ. Compliance and medicine. In: Doleys DM, Meridith RL, Ciminero AR, eds. *Behavior Medicine: Assessment and Treatment Strategies.* New York, NY: Plenum Press; 1982:527–546.
22. Bertl WH, Droschl H. Forces produced by orthodontic elastics as a function of time and distance extended. *Eur J Orthod.* 1986;8: 198–201.