Effects of Prestretching on Force Degradation Characteristics of Plastic Modules

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Synthetic elastomeric modules (usually termed plastic modules) are currently being used in several areas of orthodontics such as space closure, correction of rotations, and ligation of archwires to brackets. These modules, whose compositions are proprietary information, are placed and changed by the orthodontist at three or four-week intervals, in contrast to the older rubber latex elastics which are changed by the patient at one or two day intervals.

Numerous investigators have established that plastic modules held at fixed stretched distances in distilled water at 37°C typically lose about 50 to 75% of the initial force after one day with an additional 10% loss over three weeks.[1-5] Because of this substantial in vitro force degradation, it is suggested that orthodontists apply a large initial in vivo force to the teeth with these appliances, up to four times the desired level.

Recently Brooks and Hershey reported that prestretching the plastic modules reduced the amount of force degradation.[6] Modules prestretched for one day and immediately tested thereafter maintained 15 to 20% more of the initial force through the first day, and about 10% more of the initial force throughout a four week test period, compared with controls which were not prestretched.

The preliminary results of Brooks and Hershey suggest that prestretching might be a technique for the orthodontist to obtain plastic modules with nearly constant forces until improved materials are developed. The present experiments have been performed to investigate different prestretching environments and times in greater detail, and to assess effects of a time interval between the end of prestretching and the start of force decay testing.

Materials and Methods

Two types of orthodontic plastic modules were tested: the Alastik C Spool Chain manufactured by Unitek Corporation and the Power Chain II manufactured by Ormco Corporation. Both modules are manufactured in continuous chain form on spools; the chains were cut into individual specimen segments containing four modules each. Fixtures for stretching up to 40 specimens simultaneously were fabricated from Lexan plastic with two embedded rows of .040 inch diameter stainless steel orthodontic wire posts. The center-to-center distance between each pair of posts was .880 inch (22.4 mm), corresponding to approximately 100% stretch for the specimens and providing initial forces in the clinically useful range of 300 to 500 grams.

Force measurements were obtained with a Carpo gauge attached to a platform which could be moved across a channel on a specially designed apparatus (Fig. 1). The distance over which specimens were stretched between the two posts in this apparatus was essentially identical to the stretch distance

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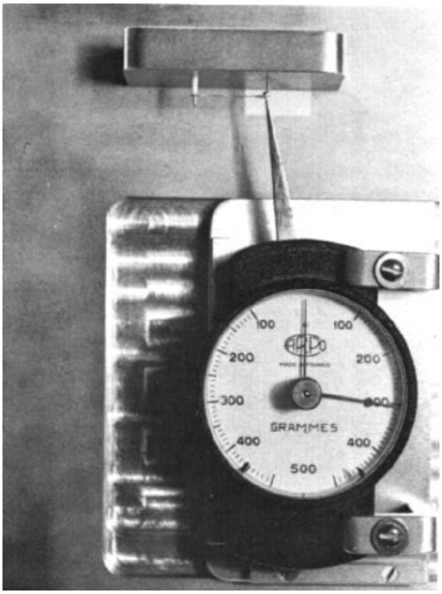

Fig. 1 Apparatus used to obtain force measurements for orthodontic plastic modules.

on the Lexan fixtures with careful allowance made for the wall thickness of the modules and the bulge at the tip of the Carpo gauge arm.

The experiments performed during this investigation are presented in Tables I and II. For each module type, measurements of force degradation in distilled water at 37°C were performed on a single test group which had not been prestretched (controls, group A) and on 10 test groups subjected to different prestretching procedures (groups B, C, D and E). Ten randomly selected specimens were selected for each test group.

Two prestretching environments were used, distilled water at 37°C (groups B and C), and air at room temperature (24°C, groups D and E), and two series of prestretching experiments were performed. In the first series (C and E), specimens were prestretched for 24 hours with measurements of force degradation starting (a) immediately and (b) 24 hours after the end of prestretching. In the second series (B and D), specimens were prestretched for three weeks with measurements of force degradation starting (a) immediately, (b) 24 hours, and (c) one week after the end of prestretching. For test groups where force degradation measurements were not initiated immediately after the end of prestretching, specimens were removed from the Lexan stretching fixtures and stored at room temperature (24°C) for the appropriate time interval.

Force measurements were made at the start and at the end of prestretching, at the start of force degradation testing (column designated Initial in the two tables), and after 1, 4 and 24 hours and 1, 2 and 3 weeks. Two hundred twenty specimens were tested during this investigation with a total of 1,860 force measurements.

Results

Effects of prestretching (PS) on the Unitek Alastik C Spool Chain and the Ormco Power Chain II specimen test groups are summarized in Tables I and II, respectively. Although experimental accuracy for repeated measurements on individual specimens is about 10 grams, average force values for each test group have been reported to three significant figures in the two tables.

Values of original force at the start of PS (or initial values for controls) for Unitek specimens (441 grams mean) were significantly ($P < .001$) higher than values for Ormco specimens (373 grams mean), using Student's t test. However, after the 3 week period of force degradation testing (right hand column in the tables) the Ormco specimens had significantly ($P < .001$) higher force values (146 grams mean) than the Unitek specimens (123 grams mean).

The control specimens (group A) were characterized by the same stress

Test Group	PS Conditions	Time after End PS to Start Test	Force at Start PS	Force at End PS	Force Values during Degradation Testing						
					Initial	1 hr	4 hr	24 hr	1 wk	2 wk	3 wk
A	Controls - No PS				423(8)	208(7)	178(6)	147(5)	125(7)	116(7)	113(5)
B	37°C Water 3 wk	0 (Immediately)	441(9)*	130(12)	130(12)	125(5)	124(5)	123(7)	122(6)	122(6)	122(6)
		24 hr	447(14)	133(5)	167(7)	123(8)	128(11)	123(7)	117(7)	116(5)	121(3)
		1 wk	439(14)	132(6)	194(12)	133(7)	122(4)	117(5)	117(5)	119(3)	119(3)
C	37°C Water 24 hr	0	444(16)	164(5)	164(5)	163(10)	158(8)	151(7)	135(7)	131(9)	129(7)
		24 hr	445(8)	166(7)	237(10)	163(4)	155(5)	147(4)	133(8)	124(8)	123(6)
D	24°C Air 3 wk	0	445(13)	258(6)	258(6)	199(9)	181(7)	145(7)	136(5)	124(5)	121(6)
		24 hr	446(8)	258(6)	343(9)	199(7)	174(7)	157(7)	128(4)	122(6)	127(5)
		1 wk	439(7)	251(9)	344(7)	204(10)	177(8)	146(5)	124(5)	134(7)	131(6)
E	24°C Air 24 hr	0	445(9)	305(14)	305(14)	209(7)	183(12)	160(9)	132(6)	128(6)	127(5)
		24 hr	437(17)	319(14)	370(9)	215(12)	191(11)	164(7)	139(11)	129(9)	123(5)

*Mean value (standard deviation). All measurements are in grams.

TABLE I
Summary of experimental results for Unitek modules.

Test Group	PS Conditions	Time after End PS to Start Test	Force at Start PS	Force at End PS	Force Values during Degradation Testing						
					Initial	1 hr	4 hr	24 hr	1 wk	2 wk	3 wk
A	Controls - No PS				374(5)	205(7)	181(3)	164(7)	144(5)	132(6)	131(6)
B	37°C Water 3 wk	0 (Immediately)	361(9)*	156(7)	156(7)	152(6)	152(4)	145(7)	149(3)	148(4)	149(3)
		24 hr	364(10)	162(8)	209(9)	154(7)	150(7)	151(7)	146(5)	142(4)	146(5)
		1 wk	358(10)	162(8)	222(6)	157(5)	149(3)	146(5)	148(4)	148(4)	146(5)
C	37°C Water 24 hr	0	393(11)	181(5)	181(5)	175(5)	171(4)	165(4)	152(5)	147(4)	148(3)
		24 hr	389(13)	190(7)	261(4)	186(6)	175(6)	170(5)	157(5)	149(2)	147(4)
D	24°C Air 3 wk	0	361(14)	244(5)	244(5)	197(9)	182(6)	164(5)	160(8)	142(4)	145(5)
		24 hr	373(7)	248(4)	317(9)	202(6)	182(8)	167(5)	159(6)	140(8)	150(0)
		1 wk	370(9)	242(12)	312(8)	201(6)	173(5)	155(7)	147(5)	150(0)	150(0)
E	24°C Air 24 hr	0	375(22)	315(13)	315(13)	200(6)	187(7)	173(10)	153(7)	145(4)	149(4)
		24 hr	386(9)	274(15)	333(7)	205(5)	189(4)	171(5)	162(9)	148(5)	145(5)

*Mean value (standard deviation). All measurements are in grams.

TABLE II
Summary of experimental results for Ormco modules.

relaxation behavior reported by previous investigators[1-5] for plastic modules in distilled water at 37°C. The most rapid loss of force occurred during the first hour with a much lower decay rate subsequently. No significant force loss for the control specimens was found after 2 weeks.

Prestretching for 3 weeks in distilled water at 37°C (group B) and then initiating force degradation testing immediately resulted in specimens which exhibited mean force losses of less than 10 grams over the 3 week test period (compare Initial and 3 week values in each table). Prestretching for 24 hours in distilled water at 37°C (group C) and initiating testing immediately yielded specimens with approximately 35 grams decrease (20%) in average force over 3 weeks. Prestretching in air at 24°C (groups D and E), even for 3 weeks, was much less effective in reducing subsequent force loss.

Loss of effects of prestretching (i.e., strain relaxation) occurred when force degradation testing was not initiated immediately. For specimens prestretched 3 weeks in distilled water at 37°C (group B, compare values of Force at End PS with Initial in the tables), the average force at the end of prestretching increased by about 30% during the 24 hours prior to the start of testing, and by approximately 40% when 1 week elapsed prior to the start of testing. For other prestretching procedures (groups C, D and E) approximately 30% and greater increases in average force generally occurred between the end of prestretching and start of testing. The only exception was the Unitek specimen group subjected to 24 hours prestretching in air at 24°C, where the mean force increased 16% from 319 to 370 grams over the 24 hour storage period.

Test groups which were subjected to the same prestretching conditions (between each pair of horizontal lines in Tables I and II) had essentially no difference (i.e., within the experimental accuracy of 10 grams) in force values after 1 hour of degradation testing regardless of the time interval between the end of prestretching and the start of testing. As with the control specimens, there was essentially no further loss in average force for any group of prestretched specimens after 2 weeks testing.

Discussion

The present results show that prestretching for 3 weeks in distilled water at 37°C yields Unitek Alastik C Spool Chain and Ormco Power Chain II four-module specimens having nearly constant forces when tested immediately after prestretching. In contrast, the two control groups lost an average of about 70% of the original force over the 3 week test period. Since specimens prestretched for 24 hours in distilled water at 37°C had only a small subsequent force loss (about 35 grams average), an intermediate prestretching time interval, probably between 24 hours and 1 week, should also yield specimens with little force loss.

Prestretching in distilled water at 37°C is therefore a technique available for the orthodontist to obtain plastic modules with nearly constant forces during clinical use until improved materials can be developed. (It should be noted that Ash and Nikolai[5] found small but statistically significant force losses after 2 and 3 weeks of testing Unitek CK and K-1 Alastiks in vivo, although no significant additional loss occurred after 1 week of testing in distilled water at 37°C). However, it is necessary to use plastic modules immediately after completion of prestretching to avoid strain relaxation. Specimens stored at room temperature (24°C) for 24 hours after prestretching in distilled water at 37°C exhibited increases of

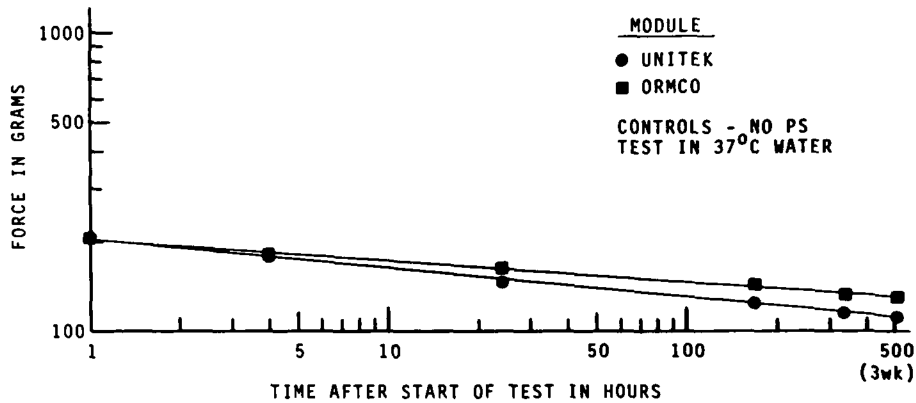

Fig. 2 Log-log plots of force degradation behavior for control specimens.

30% and greater in the average force value at the end of prestretching; additional force increases occurred after 1 week of storage. The present experiments also indicate that prestretching in air at room temperature (24°C) for times up to 3 weeks would not be a useful technique for the orthodontist, since substantial additional force losses occur during subsequent testing in distilled water at 37°C.

For each module type there was no essential difference in average force level for any of the 10 prestretching procedures after 3 weeks of testing. The test group means ranged from 119 to 131 grams for the prestretched Unitek specimens (Table I) and from 145 to 150 grams for the prestretched Ormco specimens (Table II). The two control groups exhibited lower average force values than the prestretched specimens after 3 weeks of testing, 113 grams for the Unitek and 131 grams for the Ormco specimens.

The force differences between prestretched specimens and controls after 3 weeks of testing are much less than those found by Brooks and Hershey.[6] These investigators reported that plastic modules prestretched for one day and then tested immediately maintained about 10% more of the original force throughout a 4 week test period compared with control specimens which were not prestretched. In the present study the Unitek controls maintained 27% of the original force at the end of the 3 week test period compared with an average of 28% for the prestretched specimens. The Ormco controls maintained 35% of the original force at the end of the 3 week test period compared with an average of 40% for the prestretched specimens.

The decay of average force from 1 hour to 3 weeks for the control specimens can be plotted as straight lines on log-log paper (Fig. 2). Similar force decay behavior for Unitek K2 Alastik modules at room temperature was recently reported by Kovatch et al.[7] for times from 5 seconds to 2 weeks. These straight line relationships on log-log paper indicate that over the respective testing periods the force loss can be described by a single power law expression of the form

$$\text{Force} = \text{constant} \times (\text{time})^{-n},$$

where the constant term and the fixed exponent (n) are dependent on module type and experimental conditions. Values of these parameters and the correlation coefficient (r) obtained by linear regression analysis from the log-log plots in Figure 2 are listed in Table III. Force decay kinetics for specimens subjected to prestretching and/or

TABLE III
Force Degradation Parameters for Control Specimens

Module Type	*Constant*	*n*	*r*
Unitek	205	0.097	—0.998
Ormco	203	0.071	—0.996

subsequent storage in air at 24°C, followed by testing in 37°C distilled water, are more complicated and have not been analyzed. The force degradation of specimens prestretched in 37°C distilled water is relatively small when variability of the experimental data is considered, and the decay kinetics of these specimens have also not been analyzed. Kovatch et al. have shown that both initial force values and subsequent force decay kinetics of Alastik K12 modules can be dependent on the rate of stretching.[7] It is possible that such strain rate sensitivity effects can account for some of the force variability among specimens in the present investigation.

Summary and Conclusions

This study was conducted to determine the effects of prestretching orthodontic plastic modules in greater detail than had previously been done and to assess whether a prestretching technique might yield modules with nearly constant forces. Two types of plastic modules were tested, the Unitek Alastik C Spool Chain and Ormco Power Chain II. Four-unit specimens were maintained at the same fixed stretch distance (approximately 100% extension) during prestretching and force degradation testing. A specially designed apparatus employing a Carpo gauge provided reproducible force measurements.

Two prestretching environments were used, air at room temperature (24°C) and distilled water at 37°C; all measurements of force degradation were performed in distilled water at 37°C. In the first series of prestretching experiments, specimens were prestretched for 24 hours in the two environments with force degradation measurements starting (a) immediately and (b) 24 hours after the end of prestretching. In the second series, specimens were prestretched for 3 weeks in the two environments with force degradation measurements starting (a) immediately, (b) 24 hours, and (c) 1 week after the end of prestretching. In addition, force degradation measurements were performed on 10 specimens of each module type (controls) which had not been prestretched. Force measurements were made at the start and the end of prestretching, at the initiation of force degradation testing, and after 1, 4 and 24 hours and 1, 2 and 3 weeks.

The following principal conclusions can be drawn from this investigation:

1. Prestretching in distilled water at 37°C provides a technique for the orthodontist to obtain plastic modules with nearly constant forces, but these appliances must be used immediately after prestretching to avoid substantial relaxation effects.

2. Prestretching in air at room temperature (24°C) for times up to 3 weeks is not an effective technique for obtaining plastic modules with nearly constant forces, since substantial force losses still occur with subsequent use.

3. Although the Unitek Alastik C Spool Chain specimens had higher average original force values than the Ormco Power Chain II specimens, the Ormco specimens maintained higher average forces after 1 hour and for the remainder of the test period.

4. For each module type there was no meaningful difference (within about 10 grams) in force level for any of the 10 prestretching procedures after 3 weeks of testing. Moreover, the controls and the prestretched specimens maintained essentially (within 5%) the

same amount of original force after 3 weeks.

5. The force decay kinetics of each control specimen group over the 3 week testing period followed a power law relationship. It is possible that strain rate sensitivity effects in these elastomers can account for some of the force variability among nominally similar specimens.

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