Characteristics of a fluoride-releasing elastomeric chain

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Elastomeric modules are popular with orthodontists as a means of delivering a force system for canine retraction, diastema closure, rotational corrections and contraction of dental arches. The advantages of elastomers include low cost, ease of use and, most recently with the addition of colors, a means of individual expression. However, elastomeric auxiliaries are subject to plastic deformation, that is, they do not maintain their original delivery force for a significant duration.

Andreasen and Bishara[1,2] studied the physical characteristics of elastomers and found that after 24 hours, the chains were permanently deformed by 50% of their original length with up to 74% loss of their initial force. This finding prompted the suggestion that initial force levels should be four times greater than that needed for the designed orthodontic force system. Hershey and Reynolds[3] compared a variety of elastomeric modules using a framework that simulated tooth movement and observed a 53% loss in force after 24 hours; force levels were also found to differ between manufacturers' chains. After 4 weeks, the average force remaining was 40% of the initial force without simulated tooth movement but only 25-35% with simulated tooth movement. *In vivo* studies[4] showed a greater force degradation than for elastomeric modules immersed in water at 1 week, indicating that masticatory effects, tooth brushing, salivary enzymes and oral temperature changes may affect force degradation.

Wong[5] found that the greatest force loss occurred in the first 3 hours, with some variation between manufacturers' chains, and recommended pre-stretching the elastic chains by one-

Abstract

The physical properties and fluoride releasing capabilities of a recently introduced fluoride-containing elastomeric chain (Fluor-I-Chain) have been evaluated and compared to those of a standard gray elastomeric chain.

When stored in solution, there was a progressive loss of the force delivered by both types of chains. In particular, they both required increased displacement to achieve force levels of 150g and 300g but the fluoride chain required significantly more displacement to achieve the same force level. When maintained at a constant distraction of 100%, Fluor-I-Chain was unable to deliver a force within the optimal range for tooth movement after one week. In contrast, the force delivery level of the standard gray chain remained adequate over the entire three-week test period. Fluoride was released by the fluoride-containing chain over a three-week period at a level that could inhibit demineralization and promote remineralization.

Key Words

Elastomeric module • Fluoride • Force degradation

Submitted: April 1992 **Revised and accepted for publication:** May 1993 Angle Orthod 1994; 64(3):199-210.

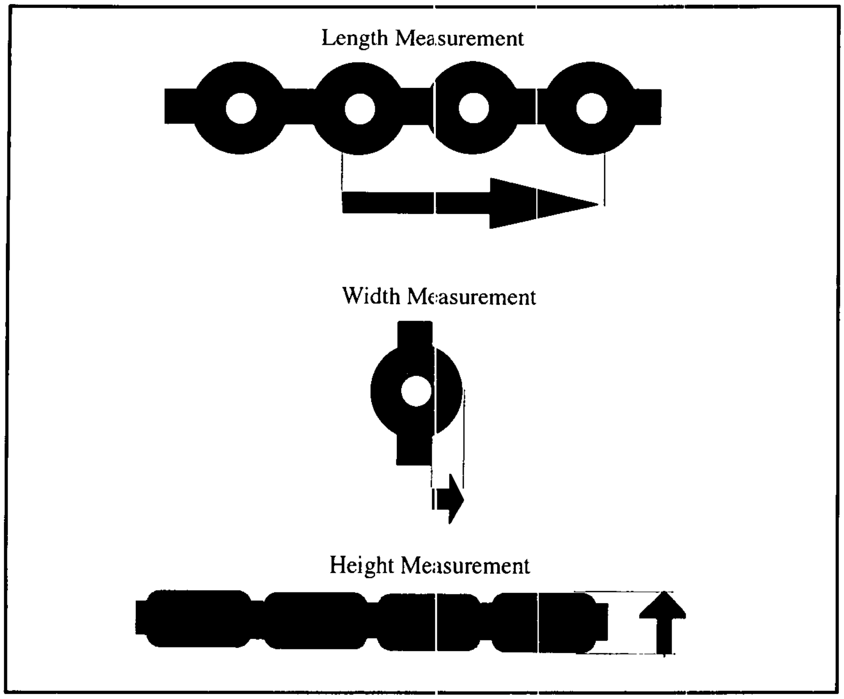

Figure 1

Figure 1
Measurement points for dimensional change determination of elastomeric chains.

third of their original length prior to placement to improve module performance. Several studies[6-9] have since looked at pre-stretching of the elastic modules and although this improved early force degradation behavior, i.e. in the first 24 hours, little difference was found at 4 weeks between force levels of pre-stretched and nonstretched chains. The effects of pre-stretching on elastomer performance, however, vary with the amount of pre-stretching, the length of the interloop filament and the specific brand of elastomeric chain. A study[10] of the force-extension characteristics of 13 commercially available chains showed that the force values at 100% extension were constant despite variations in the number of loops. It was also noted that all but one type of chain had to be extended beyond the elastic limit to provide an optimal force value for tooth movement which prompted the recommendation that chains should be extended by 50-75% of their original length for optimal force levels.

These studies clearly indicate that the physical properties of synthetic elastomers are not ideal but the incorporation of fluoride in the elastomer may offer an additional clinical advantage. The placement of fixed orthodontic appliances frequently leads to enamel demineralization or white spot formation around orthodontic bands and brackets.[11-16] Fluoride has long been known to reduce the incidence of tooth decay[17-20] although the amount of fluoride required to inhibit enamel demineralization is dependent upon the driving force for demineralization. Fluoride concentrations of less than 0.05 ppm have been shown to reduce the rate of caries formation[21-24] and a level of 1 ppm effects a two- to threefold increase in the rate of precipitation of fluoridated hydroxyapatite.[24-25] With higher fluoride levels, the enamel surface can experience precipitation of CaF_2, the latter acting as a fluoride reservoir with variable dissolution rates due to impurities incorporated during its precipitation.[26] Nevertheless, any elevation of salivary fluoride helps prevent demineralization although exogenous fluoride sources require frequent application because of salivary clearance.[27] While topical fluoride treatments are effective in reducing the incidence of demineralization around orthodontic appliances,[28-30] there tends to be poor compliance with the convenient and cost-effective home-care programs.[31]

A commercial company recently developed and began marketing an elastomeric module, Fluor-I-Chain (Ortho Arch, Hoffman Estates, Illinois), which they claim is capable of releasing low concentrations of fluoride. This type of product may provide the orthodontist with a means of applying fluoride independent of patient cooperation. Accordingly, it was decided to evaluate the elastic properties of the fluoride-containing chain in comparison to those of a standard closed loop elastomeric chain to determine whether the presence of fluoride adversely affected the elastic properties. In particular, the tensile characteristics, dimensional change, force degradation and the effect of pre-stretching were examined. In addition, the fluoride-delivery capabilities of this elastomeric module were also evaluated to assess the potential anti-caries efficacy of the elastomeric module.

Materials and methods

A fluoride-containing elastomeric chain, Fluor-I-Chain, and a conventional closed loop gray chain were obtained from Ortho Arch Company (Ortho Arch, P.O. Box 676, Hoffman Estates, IL. 60195) for comparison of their mechanical properties. The fluoride-releasing characteristics of Fluor-I-Chain were also evaluated.

Tensile studies

Specimens for tensile testing comprised four-link sections of the two types of chain, half of which were pre-stretched by 50% of their original length, the remainder being tested in their as-received state. All specimens then were stored at 37±1°C in sealable plastic vessels that contained air, distilled water or an artificial saliva, Oralube. A total of 60 pieces of chain, 30 Fluor-I-Chain and 30 gray mandibular chain, were tensile tested at time intervals of 1, 4 and 24 hours and 1, 2 and 3 weeks to determine the displacement required to

Table 1
Gray Chain: Distraction (mm) to deliver a force of 150 g

	1 hour	4 hours	24 hours	7 days	14 days	21 days
AIR						
Unstretched	3.16±.19	3.18±.21	3.04±.19	3.12±.16	2.98±.16	3.10±.13*
Stretched	3.38±.10	3.12±.12	3.12±.19	3.10±.11	3.14±.05	3.38±.20
WATER						
Unstretched	3.18±.28	3.22±.12	3.14±.10	3.24±.08	3.24±.05	3.24±.16
Stretched	3.16±.10	3.26±.19	3.36±.14	3.44±.12	3.24±.14	3.5±.17
ORALUBE						
Unstretched	3.10±.11	3.46±.10	3.44±.05	3.44±.10	3.38±.04	3.60±.25
Stretched	3.26±.22	3.48±.12	3.58±.16	3.64±.10	3.60±.17	3.70±.26

Fluor-I-Chain: Distraction (mm) to deliver a force of 150 g

	1 hour	4 hours	24 hours	7 days	14 days	21 days
AIR						
Unstretched	2.84±.19	3.02±.13	2.82±.12	2.88±.10	2.74±.12	2.86±.14
Stretched	2.98±.16	2.98±.16	2.86±.12	2.80±.14	2.86±.08	3.32±.07
WATER						
Unstretched	3.42±.21	3.42±.13	3.58±.07	4.12±.20	4.08±.23	4.34±.21
Stretched	3.36±.27	3.56±.26	3.70±.14	3.96±.12	4.08±.17	4.14±.17
ORALUBE						
Unstretched	3.08±.19	3.42±.26	3.66±.23	3.88±.29	4.12±.19	4.34±.20
Stretched	3.30±.22	3.36±.10	3.54±.28	3.82±.04	4.02±.21	4.36±.19

*: Mean value ± standard deviation

obtain 150 g and 300 g of force. All tests were performed in triplicate.

Tensile testing was performed on a universal testing machine (Unite-O-Matic FM 20, United Calibration Corporation, Garden Grove, Calif). Each sample was placed in a test jig comprising two metal pins attached respectively to the fixed and movable crossheads of the tensometer and loaded in tension at a crosshead speed of 50 mm/min until the chain broke. The displacements of the chains required to produce 150 g and 300 g force were measured from the force-displacement curve of each sample as recorded by the load transducer and the internal chart recorder of the tensometer.

Dimensional change

The dimensions, i.e. length, width and height, of all specimens in the as-received state and immediately prior to each tensile test were measured with a linear vernier microscope (Griffin and George, London, UK). The sites of dimensional measurements are shown in Figure l.

Force degradation

Force degradation was studied by placing 10 four-link sections of both types of chain on a three-quarter inch thick plexiglass testing block that contained opposing sets of hooks. The lower hooks were fixed while the separation between the hooks could be adjusted by vertical movement of the upper hooks, which could then be locked in place by stops resting on the upper platform of the jig. After each test specimen of chain was placed on a single pair of hooks, the chains were stretched to 100% of their original length and maintained at this distraction by the stops on the upper hooks. The test block then was stored in distilled water at 37±1°C for a total period of 3 weeks. Each sample was tensile tested with the universal testing machine at a crosshead speed of 5 mm/min until the stop was lifted from the jig, testing being performed at the initial placement (immediate or initial level), at 4 and 24 hours, and at 1, 2 and 3

Table 2
Gray Chain: Distraction (mm) to deliver a force of 300 g

	1 hour	4 hours	24 hours	7 days	14 days	21 days
AIR						
Unstretched	6.72±.19	7.00±.18	6.64±.20	6.76±.22	6.36±.23	6.92±.19*
Stretched	7.16±.12	7.00±.22	6.90±.21	6.96±.23	6.88±.26	7.30±.37
WATER						
Unstretched	7.04±.49	7.08±.10	7.00±.14	7.06±.12	7.04±.08	7.42±.50
Stretched	6.88±.16	7.16±.17	7.26±.05	7.26±.08	7.16±.10	7.48±.57
ORALUBE						
Unstretched	6.50±.14	7.52±.21	7.52±.21	7.38±.15	7.52±.07	7.56±.29
Stretched	6.92±.20	7.64±.24	7.62±.12	7.56±.21	7.56±.19	7.90±.11

Fluor-I-Chain: Distraction (mm) to deliver a force of 300 g

	1 hour	4 hours	24 hours	7 days	14 days	21 days
AIR						
Unstretched	6.20±.27	6.36±.23	6.18±.12	6.14±.08	6.06±.10	6.18±.16
Stretched	6.32±.19	6.34±.22	6.16±.22	6.10±.06	6.08±.23	6.64±.26
WATER						
Unstretched	7.42±.30	7.46±.16	7.68±.32	8.12±.31	8.06±.05	8.38±.29
Stretched	7.42±.28	7.58±.32	7.90±.21	8.06±.26	8.00±.22	8.34±.31
ORALUBE						
Unstretched	7.04±.36	8.10±.23	8.06±.54	8.16±.35	8.28±.17	8.88±.37
Stretched	7.34±.45	7.60±.21	7.90±.30	8.24±.21	8.24±.20	8.56±.19

*: Mean value ± standard deviation

weeks. The force required to lift the stop was recorded by the load transducer and the internal chart-recorder of the tensometer.

Fluoride release

The amount of fluoride released from Fluor-I-Chain was determined for five samples of four-loop sections of chain. Specimens were stretched by 50% of their original length on a 0.036 inch stainless steel wire and placed into 15 ml distilled water in sealable plastic containers at 37±1°C. Fluoride levels for each specimen were recorded at intervals of 1, 4 and 24 hours and 1, 2, and 3 weeks. At each time period, the chain was removed from the container and placed in a new plastic container with 15 ml distilled water.

Fluoride concentration was determined with a Hach Model 19200 laboratory pH/ion meter. The distilled water used as the storage media was found to have a standard fluoride concentration of 0.15±0.01 mg/l of fluoride.

Statistical analysis

Mean values and their standard deviations were computed for all specimens and all test regimens. After this, the tensile and dimensional test data were subjected to multifactor ANOVAs. Interactions above the second order were considered clinically and scientifically un-interpretable and collapsed into the error term. Second order interactions were analyzed using the Bonferroni simultaneous t-test with a familywise *a priori* $\alpha = 0.05$.[32,33]

The force degradation data were analyzed by a univariate repeated measures analysis. Second order interactions found to be significant ($p<0.05$) were confirmed with the Wilk and Hotelling multivariate repeated measure analysis for within group factors.[32,33]

Means and standard deviations of fluoride release were calculated at each test period and compared graphically.

Table 3
Gray Chain: Specimen length (mm) and % change with time

	1 hour	4 hours	24 hours	7 days	14 days	21 days
AIR						
Length	7.73±.06	7.70±.07	7.72±.06	7.78±.05	7.64±.09	7.70±.09*
% Change		-0.39	-0.01	0.65	-1.16	-0.39
WATER						
Length	7.72±0.1	7.79±.09	7.75±.07	7.72±.06	7.72±.06	7.70±0.14
% Change		0.91	0.39	0.00	0.00	-0.26
ORALUBE						
Length	7.72±.09	7.93±.08	8.22±.08	8.27±.09	7.94±.07	7.78±.22
% Change		2.72	6.48	7.12	2.85	0.78

*: Mean value ± standard deviation

Table 4
Fluor-I-Chain: Specimen length (mm) and % change with time

	1 hour	4 hours	24 hours	7 days	14 days	21 days
AIR						
Length	7.75±.08	7.76±.10	7.64±.09	7.73±.06	7.69±.12	7.75±.12*
% Change		0.13	-1.42	-0.26	-0.77	0.00
WATER						
Length	7.75±.18	7.81±.03	7.95±.13	8.71±.08	10.21±.08	10.40±.15
% Change		0.77	2.58	12.39	31.74	34.19
ORALUBE						
Length	7.85±.09	7.87±.10	8.16±.23	9.86±.26	10.01±.09	10.50±.16
% Change		0.25	3.95	25.61	27.52	33.76

*: Mean value ± standard deviation

Results

Tensile Study

Both elastomeric chains required a distraction of 3 mm to deliver a force of 150 g and 7 mm to deliver a force of 300 g A 10% change in the required distraction to deliver the same force would necessitate stretching an elastic module by 3.3 mm and 7.7 mm to deliver 150 and 300 g respectively, that is, a negligible increase and one that would not be detectable under most circumstances. Accordingly, clinical significance, in contradistinction to statistical significance, will only be commented upon when the observed increase in displacement exceeds 10%. The tensile data are summarized in Tables 1 and 2.

Fluor-I-Chain stored in air showed no significant ($p>0.05$) difference in the distraction required for a 150 g or 300 g force throughout the test period but there was a gradual and statistically significant increase ($p<0.05$) in distraction to achieve a 150 g and 300 g force when stored in water and Oralube over the 21 day test period.

A statistically significant ($p<0.05$) increase in required distraction for the gray mandibular chain was found only with chains stored in Oralube. This increase occurred at the 4 hour test period for both the 150 g and 300 g force levels and continued to the conclusion of testing.

When the tensile characteristics of the two types of chain were compared for specimens stored in air, the distraction required for a 150 g or 300 g force was significantly ($p<0.05$) less for Fluor-I-Chain than gray mandibular chain throughout the 3 week test period. The reverse was true for chains stored in solution. Beginning at the four hour test period and continuing through three weeks, Fluor-I-Chain required a significantly ($p<0.05$) greater displacement for both 150 g and 300 g force levels than gray mandibular chain.

Pre-stretching

The data showed no clinical significance (i.e. a change >10%) in the distraction to deliver a force

Table 5
Force delivery in grams at a distraction of 100% and percentage of initial load

TIME	0	4hours	24hours	7days	14days	21days
Fluor-I-Chain						
Force	316.3±25.6	188.2± 4.4	122.4± 2.8	43.2± 2.0	26.5± 1.4	20.4± 1.2*
Per cent	100	59.5	38.7	13.7	8.4	1.2
Gray Chain						
Force	279.6±18.2	164.6±5.2	127.1±4.3	106.9±3.9	101.2±4.6	97.5±4.0
Per cent	100	58.9	45.5	38.3	36.2	34.9
Difference**	p<0.05	p<0.05	nS	p<0.05	p<0.05	p<0.05

*: Mean value ± standard deviation
**: Significance of difference between mean force levels.

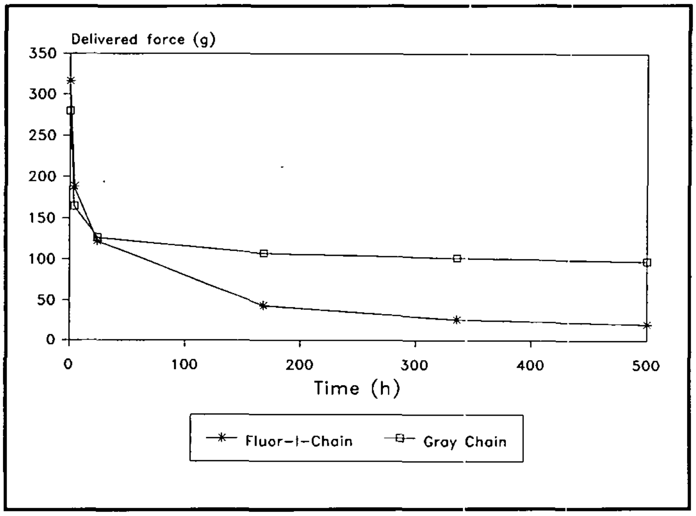

Figure 2

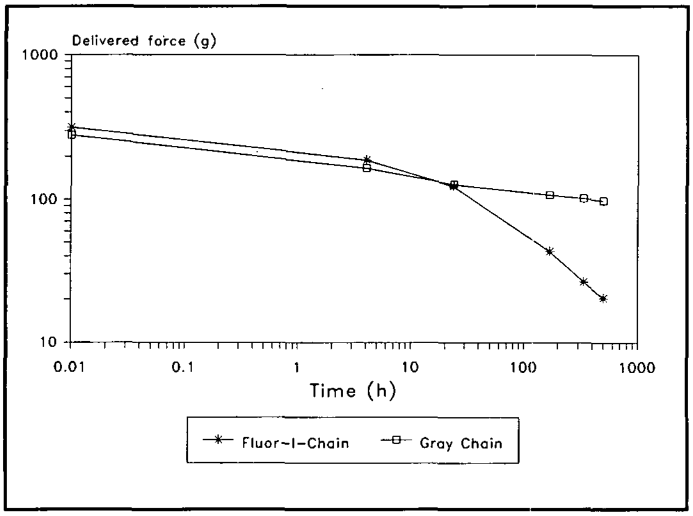

Figure 3

Figure 2
Delivered force vs time behavior for gray chain and Fluor-I-Chain elastomeric modules.

Figure 3
Logarithm of delivered force vs logarithm of time behavior for gray chain and Fluor-I-Chain elastomeric modules.

of 150 g or 300 g when either Fluor-I-Chains or the gray mandibular chains were pre-stretched by 50% of their original length for five seconds prior to the testing.

Dimensional Change

Although many statistically significant changes in size were noted, for the purposes of making the result clinically applicable, only those changes greater than 10% are considered relevant for the present discussion. Changes in the chain length are presented in Tables 3 and 4. Similar changes in the width and height of both chains were observed.

Fluor-I-Chain showed an increase in all three dimensions when stored in Oralube and water; the increase became significant (p<0.05) at approximately one week and gradually continued until the conclusion of testing at 3 weeks. In contrast, the dimensional increase in Grey chain did not exceed 10% over the test period.

When the two chains were compared, Fluor-I-Chain had a significantly (p<0.05) greater size than gray mandibular chain beginning at the one week test period. This size difference between the two chains continued to increase until the conclusion of testing at 3 weeks.

Force Degradation

The force degradation data are given in Table 5 and Figures 2 and 3. Fluor-I-Chain exhibited a very rapid loss of force over the first week of testing, with a slower rate of force thereafter. The difference in force delivery at each time interval was statistically significant (p<0.05) over the first 2 weeks. No significant (p>0.05) difference in force levels were seen between the 2 and 3 week test periods. Gray mandibular chain also exhibited a rapid loss of force over the first week with a significant (p<0.05) difference in the force delivery between each test interval. There was, however, no change (p>0.05) in force delivery between the first through the third week.

Comparing the two chains, Fluor-I-Chain

Table 6
Fluoride release (mg/l) by a four loop length of Fluor-I-Chain elastomeric module
(Total fluoride release: 2.94 mg/l)

TIME	1hour	4hours	24hours	7days	14days	21days
Fluoride	0.49 ±0.03	0.32 ±0.06	0.88 ±0.07	0.95 ±0.09	0.25 ±0.07	0.06 ±0.02*
Per cent	17.0	27.9	57.8	90.1	98.3	100

*: Mean value ± standard deviation

showed a significantly ($p<0.05$) greater force level at the initial and 4 hour test periods. However, there was no significant ($p>0.05$) difference in force levels between the two chains at the 24 hour time interval, but from 1 week to the conclusion of testing, gray mandibular chain delivered a significantly ($p<0.05$) greater force level than the Fluor-I-Chain for the same distraction.

Fluoride Release

The data for fluoride released from Fluor-I-Chain are shown in Table 6 and Figure 4. At 24 hours, a mean of 1.69 mg/l or approximately 57% of the chain's total fluoride content had been released. At 1 week, the mean fluoride release was 2.65 mg/l, approximately 90% of the total fluoride released over the three week testing period. The mean total fluoride released from the five samples at the three week test period was 2.94 mg/l.

Discussion

The literature contains many references to the decrease in force delivery by elastomeric modules over time and this characteristic makes it difficult to predict their active force delivery levels. Nevertheless, in clinical use, elastomeric modules appear to satisfy the force requirements for tooth movement in many applications.

The present study compared the effects of storage in air, water and artificial saliva (Oralube) on initial force-displacement behavior of these two types of chain over a 3 week period. Fluor-I-Chain was found to require a greater distraction to obtain a 150 g and 300g force when immersed in Oralube and water than when stored in air. This increase in distraction was between 22-40% for a force of 150 g and 12-36% to maintain a 300 g force. Gray mandibular chain was found only to require an increase in distraction when immersed in Oralube. This increase was approximately 16% to maintain either a 150 g or 300 g force. Although these increases were statistically significant for both chains, it is unlikely that they would be clinically relevant for gray mandibular chain because such an increase, approximately 0.4 and 1.0 mm at these force levels, is too small for clinical concern. For Fluor-I-Chain, the increase in displacement could have clinical relevance in the upper range and, in contrast to gray mandibular chain, this elastomer would require a distraction of one third its length to maintain an equal force.

Inspection of the distraction data revealed certain general trends. For Fluor-I-Chain, changes in the required displacement for forces of 150 g and 300 g began to occur at the 4 hour test period. Gray mandibular chains immersed in Oralube also had displacement changes beginning at the 4 hour test period for 150 g and 300 g of force. Between 4 hours and 21 days a progressive increase in displacement was needed to achieve the required force levels for Fluor-I-Chain , while gray mandibular chain required only a slight displacement increase. This supports the findings of previous studies.[5,8,34]

The effect of pre-stretching Fluor-I-Chain and gray mandibular chain by 50% of their initial length for 5 seconds prior to testing for displacement at 150 g and 300 g of force was also studied. For both chains, no clinically relevant (i.e.>10%) difference was seen between the pre-stretched chain and those that were not pre-stretched. This finding differs from that reported by previous studies,[6-9] although these earlier results did show variation between manufacturers' chains.

In general, Fluor-I-Chain exhibited considerable dimensional increase when immersed in Oralube and water. These dimensional changes generally began at 1 week and continued to the conclusion of testing and ranged from 34-45% for Oralube and 11-37% for water. This increase in dimension of Fluor-I-Chain probably results from the absorption of fluids as fluoride is released. The dimensional changes may cause a degradation in force and account for some of the additional displacement required of Fluor-I-Chain to produce a force equal to that delivered by gray mandibular chain. For gray mandibular chain, the change in size was found to be clinically irrelevant, and would be unlikely to substantially affect the initial displacement requirements or force degradation

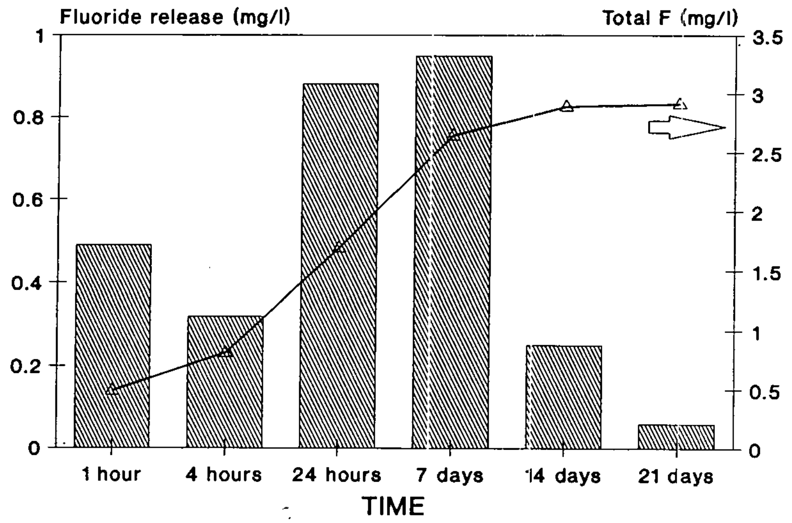

Figure 4

Figure 4
Histogram bars indicate mean fluoride release by Fluor-I-Chain over a three week period, curve denotes total fluoride release over the test period.

Table 7

Time (days)	Observed force (g)	Calculated force (g)
Grey chain		
0	279.6	275.4
0.17	164.6	160.1
1	127.1	132.4
7	106.9	107.8
14	101.2	100.1
21	97.5	95.9
Fluor-I-chain		
0	316.3	316.2
0.17	188.2	180.1
1	122.4	125.9
7	43.2	42.4
14	26.5	26.3
21	20.4	19.8

of the chain.

A second major area of study was force degradation where equal lengths of chain were stretched to 100% of their original length and maintained at this distraction for 3 weeks. Fluor-I-Chain was found to deliver an initial mean force of 316 g and gray mandibular chain 280 g. Both of these force levels are within the optimal force range for tooth movement described by previous studies.[35-38]

At 24 hours, mean force levels for both chains were the same although Fluor-I-Chain retained only 39% and gray mandibular chain 45% of the remaining initial force. These findings for force decay at 24 hours are comparable to those previously reported.[1-3,5] By 1 week, the Fluor-I-Chain force level had dropped to 43 g or 14% of its initial force, a force level, as indicated by Boester and Johnston,[35] that would not be adequate to retract a canine. In contrast, the gray mandibular chain provided a mean force level of 107 g which remained relatively constant throughout the 3 week test.

In terms of its mechanical properties, Fluor-I-Chain may not be an adequate replacement for gray mandibular chain because it cannot provide the force levels required for tooth movement over a normal treatment regimen. More frequent changing of Fluor-I-Chain would not be a satisfactory solution to this problem because of the increased treatment time, cost and inconvenience to the practitioner and patient.

One note of significance when looking at load degradation behavior is that the force delivery-time behavior of gray chains follows the relationship:

$$\text{Force (g)} = \frac{132}{(\text{days})^{0.13}}$$

The force delivery-time behavior of Fluor-I-chain over the period 0 to 1 day follows the relationship:

$$\text{Force (g)} = \frac{126}{(\text{days})^{0.2}}$$

however, over the period 7 to 21 days, it follows the relationship:

$$\text{Force (g)} = \frac{162}{(\text{days})^{0.69}}$$

The observed and calculated forces for the two chains are given in Table 7 and were found to be remarkably predictable:

The amount and rate of fluoride release from Fluor-I-Chain was interesting. A mean fluoride release of 2.94 mg/l was observed over the three week test. Of this total amount, 57% leached out in the first 24 hours. By 1 week, a mean of 2.65 mg/l or 90% of the fluoride had been leached out so that for the last 2 weeks, the mean fluoride release was only 0.29 mg/l. However, these data were obtained with only one elastomeric chain of four loops. In a clinical situation one would anticipate the simultaneous use of two to four chains during treatment, in effect doubling or quadrupling the amount of fluoride available. Although it is obvious that most of the fluoride is leached out in 1 week, past studies have shown that the concentration of fluoride required to inhibit demineralization can be less than 0.05 ppm.[21-24] It follows that the clinical use of Fluor-I-Chains may be effective in caries prophylaxis because the low levels of fluoride released from 1 week to 3 weeks could still have an inhibitive effect on caries. Further, with the initial rapid release of fluoride, one could expect formation of calcium fluoride on the enamel surface.[26] The incorporation of impurities in calcium fluoride at the time of formation would vary the dissolution rates and enable calcium fluoride to act as a fluoride reservoir.[26]

Fluoride has been shown to have a high affinity for demineralized areas.[39-40] If, at the initiation of orthodontic treatment, there were incipient demineralized lesions present, the initial high concentration of fluoride would inhibit further demineralization and increase the re-mineralized enamel's resistance to secondary acid attack.[41,42]

Even though Fluor-I-Chain would not adequately replace gray mandibular chain on the basis of physical properties, further investigation should be undertaken with fluoridated elastomeric ligature ties. If the latter were found to release adequate amounts of fluoride, their use as ligature ties would provide the practitioner with a fluoride delivery system independent of patient cooperation.

Conclusions

The findings of this study permit several conclusions:

1. Fluor-I-chain was found to require increased distraction to achieve 150g and 300g forces when immersed in liquid media. Gray mandibular chain only required an increase in displacement for a 150g and 300g force when immersed in Oralube. The increase in displacement of gray mandibular chain is not felt to be clinically relevant, but the required increase in displacement of Fluor-I-Chain could be as much as one-third of its original length.

2. Water and Oralube significantly affected Fluor-I-Chain's initial force displacement beginning at 4 hours of immersion.

3. Pre-stretching Fluor-I-Chain or gray mandibular chain had no clinical relevance on initial distraction requirements for a 150g or 300g force.

4. Approximately 3 mg of fluoride is released from the Fluor-I-Chain over a 3 week test period, 50% of which is leached out in the first 24 hours and 90% within the first week.

5. Fluor-I-Chain does release fluoride over a 3 week period at a level that could have the potential to inhibit demineralization and promote remineralization.

6. The initial force levels of Fluor-I-Chain and gray mandibular chain when stretched by 100% their original length were 316g and 280g respectively. After 1 week, Fluor-I-Chain's force level had degraded to 43 g or 14% of its original force. This force level would not be adequate to retract a canine. Gray mandibular chain at one week had a force level of 107 g which remained fairly constant through the remaining 2 weeks.

Acknowledgments

The authors of this study would like to give special thanks to Mr. Randall Storey for his technical assistance with this project.

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The views expressed in this paper are exclusively those of the authors and do not reflect those of the United States Army Dental Corps, the United States Army, or the Department of Defense.

References

1. Andreasen, GF, Bishara, SE: Comparison of Alastic Chains and Elastics Involved with Intra-Arch Molar to Molar Forces. Angle Orthod 40:151-158, 1970.
2. Bishara, SE, Andreasen, GF: Relaxation of Orthodontic Elastomeric Chains and Modules In Vitro and In Vivo. Angle Orthod 40:319-328, 1970.
3. Hershey, G, Reynolds, W: The Plastic Module as an Orthodontic Tooth Moving Mechanism." Am J Orthod 67:554-562, 1975.
4. Ash, J, Nikolai, R: Relaxation of Orthodontic Elastic Chains and Modules In Vitro and In Vivo. J Dent Res 57:685-690, 1978.
5. Wong, A: Orthodontic Elastic Materials. Angle Orthod 46:196-205, 1976.
6. Brantley, W, Salander, S, Myers, L, Winders, R: Effects of Pre-stretching on Force Degradation Characteristics of Plastic Modules. Angle Orthod 49:37-43, 1979.
7. Brooks, D, Hershey, H: Effect of Heat and Time on Stretched Plastic Orthodontic Modules. J Dent Res 55B:363, 1976.
8. Williams, J, von Fraunhofer, JA: Degradation of the Elastic Properties of Orthodontic Chains. MS Thesis Research Project, University of Louisville, 1990.
9. Young, J, Sandrik, J: The Influence of Preloading on Stress Relaxation of Orthodontic Elastic Polymers. Angle Orthod 49:104-109, 1979.
10. Rock, WP, Wilson, HJ, Fisher, S: A Laboratory Investigation of Orthodontic Elastomeric Chains. Br J Orthod 12:202-207, 1985.
11. Gorelick, L, Geiger, AM, Gwinnett, JA: Incidence of White Spot Formation After Bonding and Banding. Am J Orthod 81:93-98, 1982.
12. Ingervall, B: The Influence of Orthodontic Appliances on Caries Frequency. Odontol Revy 13:175-190, 1962.
13. Mizrahi, E. "Enamel Demineralization Following Orthodontic Treatment." Am J Orthod 82:62-67, 1982.
14. Mizrahi, E. Surface Distribution of Enamel Opacities Following Orthodontic Treatment. Am J Orthod 84:323-331, 1983.
15. Wisth, PJ, Nord, A: Caries Experience in Orthodontically Treated Individuals. Angle Orthod 47:59-64, 1977.
16. Zachrisson, BU, Zachrisson S: Caries Incidence and Orthodontic Treatment with Fixed Appliances. Scand J Dent Res 79:83-192, 1971.
17. Arnold, FA, Likins, RC, Russell, AL, Scott, DB: Fifteenth Year of the Grand Rapids Fluoridation Study. J Am Dent Assoc 65:780-785, 1962.
18. Dean, HT, Arnold, FA, Elvove, E: Domestic Water and Dental Caries. Public Health Res 53:1443-1452, 1938.
19. Dean, HT, Arnold, FA, Jay, P, Knutson, JW: Studies on Mass Control of Dental Caries Through Fluoridation of the Public Water Supply. Public Health Res 65:1403-1408, 1950.
20. Englander, HR, Wallace, DA: Effects of Naturally Fluoridated Water on Dental Caries in Adults. Public Health Res 77:887-893, 1962.
21. Margolis, HC, Mareno, EC, Murphy, BJ: Effect of Low Levels of Fluoride in Solution on Enamel Demineralization in Vitro. J Dent Res 65:23-29, 1986.
22. Ten Cate, JM, Duijsters, PPE: Influence of Fluoride Solution on Tooth Demineralization. I. Chemical Data. Caries Res 17:193-199, 1983

23. Ten Cate, JM, Duijsters, PPE: Influence of Fluoride Solution on Tooth Demineralization. II Microradiographic Data. Caries Res 17:513-519, 1983.
24. Ten Cate, JM: In Vitro Studies on the Effects of Fluoride on De- and Remineralized Enamel. J Dent Res 69 (Special Issue):614-619, 1990.
25. Ten Cate, JM, Arends, J: Remineralization of Artificial Enamel Lesions in Vitro. Caries Res 11:277-286, 1977.
26. Rolla, G, Saxegaaro, E: Critical Evaluation of the Composition and Use of Topical Fluorides, with Emphasis on the Role of Calcium Fluoride in Caries Inhibition. J Dent Res 69 (Special Issue):780-785, 1990.
27. Dawes, C, Weatherbell, JA: Kinetics in the Oral Fluids. J Dent Res 69 (Special Issue):638-644, 1990
28. Flaitz, CM, Hicks, JM: Effects of Sodium Fluoride and Stannous Fluoride Solution on Caries-Like Lesion Formation Around Adhesive Orthodontic Brackets: An in Vitro Study." Quintessence Int 19:117-123, 1988.
29. Stratemann, MN, Shannon, IL: Control of Decalcification in Orthodontic Patients by Daily Self Administered Application of a Water-Free .04% SnF2 Gel. Am J Orthod 66:273-279, 1974.
30. Muhler, JC: Dental Caries-Orthodontic Appliance-SnF_2. J Dent Child 37:218-221, 1970.
31. Geiger, A, Gorelick, L, Gwinnett, JA, Griswold, PG: The Effect of a Fluoride Program on White Spot Formation During Orthodontic Treatment. Am J Orthod 93:29-37, 1988.
32. Miller, R: Simultaneous Statistical Inferine, 2nd ed. New York: Springer-Verlag. 1981.
33. Neter, J, Wasserman, W, Kutner, M: Applied Linear Statistical Models, 2nd ed. Homewood, Il: Richard D. Irwin, Inc., 1985.
34. von Fraunhofer, JA, Coffelt, M, Orbell, M: The Effects of Artificial Saliva and Topical Fluoride Treatments on Degradation of the Elastic Properties of Orthodontic Chains. Angle Orthod - In Press.
35. Boester, C, Johnston, L: A Clinical Investigation of Concepts of Differential and Optimal Force in Canine Retraction. Am J Orthod 44:113-119, 1974.
36. Hixon, E, Atikian, H, Callow, G, McDonald, H, Tracy, R: Optimal Force, Differential Force, and Anchorage. Am J Orthod 55:437-457, 1969.
37. Hixon, E, Aasen, T, Arango, J, Clark, R, Klosterman, R, Miller, S, Odom, W: One Force and Tooth Movement. Am J Orthod 57:476-485, 1970.
38. Storey, E, Smith, R: Forces in Orthodontics and Its Relation to Tooth Movement. Aust J Dent 56:11-18, 1952.
39. Hallsworth, AS, Robinson, C, Weatherell, JA: Chemical Pattern of Carious Attack. J Dent Res 50:664, 1971.
40. Sakkab, NY, Cilley, WA, Haberman, JP: Fluoride in Deciduous Teeth from an Anti-Caries Clinical Study. J Dent Res 63:1201-1205, 1984.
41. White, DJ: Reactivity of Fluoride Dentifrices with Artificial Caries. I. Effects on Early Lesions: F Uptake, Surface Hardening and Remineralization. Caries Res 21:126-140,1987.
42. White, DJ: Reactivity of Fluoride Dentifrices with Artificial Caries. II. Effects on Subsurface Lesions: F Uptake, F Distribution, Surface Hardening, and Remineralization. Caries Res 22:29-36, 1988.