# The effects of artificial saliva and topical fluoride treatments on the degradation of the elastic properties of orthodontic chains

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The magnitude, frequency, direction, moment to force ratio, constancy and range of activation are characteristics of an orthodontic force system and affect the type of biologic response in tooth movement.[1] It is now generally accepted that efficient physiologic correction of a dental malocclusion occurs through the application of light, continuous forces.[2-6] Orthodontic appliances are required to deliver a light continuous force regardless of the distance the tooth has moved.

There are a variety of force systems that can produce optimal force levels to move teeth through alveolar bone but many of the established techniques are less than optimal in terms of efficiency and practicality. Closure of spaces in the dental arch, for example, may be accomplished with closed coil springs, open coil springs, retraction springs, closing loop archwires, elastomeric chains and threads, and more recently, magnets. Coiled springs are difficult to keep clean, retraction springs and closing loop archwires can impinge the patient's gingiva and irritate mucosa. Magnets currently in use are bulky, expensive and also difficult to keep free of food debris. In contrast, elastomeric chains are economical and easy to use, do not require patient cooperation and are relatively hygienic.

Despite the widespread use of elastomeric chains in clinical practice, there are relatively few studies describing their characteristics and behavior. Elastomers undergo stress-relaxation, a decrease in the

**Abstract**

The effect of artificial saliva and topical fluoride treatments on the force relaxation and change in force delivery by three brands of elastomeric chains over a 4 week period was studied. The effect of storage in air and in the different test media on the distraction to achieve forces of 150g and 300g was determined for the chains. The effect of the test media on load relaxation of the chains was also examined.

Elastomeric chains exhibit good elastic behavior when distracted to an initial force of less than 300g. When forces exceeded 300g, permanent deformation occurred and the force delivery was less predictable. Exposure to artificial saliva and topical fluoride affected the elastic properties of the elastomeric chains and increased the distraction required to deliver both the 150g and 300g force. The increase in distraction for a force of 150g, however, was relatively small and probably insignificant in the clinical setting. The distraction required to produce 300g was significantly larger and appeared to be clinically significant. Pre-stretching the elastomeric chains by 100% of their initial length was not found to be advantageous in terms of the load relaxation behavior. There was less load relaxation found in chains that were immersed in distilled water and Acidulated Phosphate Fluoride than in chains exposed only to air.

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**Key Words**

Elastomeric chains • Elastic properties • Load relaxation • Fluoride • Artificial saliva

**Table 1**
**Ormco Generation II Power Chain**

**Displacement (in mm) to deliver forces of 150g and 300g**

| Time (hours/days) | 0 | 4h | 24h | 7d | 14d | 21d | 28d |
|---|---|---|---|---|---|---|---|
| **AIR** | | | | | | | |
| 150g | | | | | | | |
| Mean | 3.1 | 3.1 | 3.1 | 3.0 | 3.2 | 3.1 | 3.2 |
| Std. Dev. | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 |
| % Increase | | 0.0 | 0.0 | -3.2 | 3.2 | 0.0 | 3.2 |
| 300g | | | | | | | |
| Mean | 7.5 | 7.6 | 7.5 | 7.5 | 7.6 | 7.6 | 8.0 |
| Std. Dev. | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 |
| % Increase | | 1.3 | 0.0 | 0.0 | 1.3 | 1.3 | 6.7 |
| **WATER** | | | | | | | |
| 150g | | | | | | | |
| Mean | 3.1 | 3.4 | 3.7 | 3.5 | 3.5 | 3.4 | 3.4 |
| Std. Dev. | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 |
| % Increase | | 9.7 | 19.4 | 12.9 | 12.9 | 9.7 | 9.7 |
| 300g | | | | | | | |
| Mean | 7.5 | 8.4 | 9.3 | 8.2 | 8.8 | 8.4 | 9.0 |
| Std. Dev. | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | 0.4 |
| % Increase | | 12.0 | 24.0 | 9.3 | 17.3 | 12.0 | 20.0 |
| **KCL** | | | | | | | |
| 150g | | | | | | | |
| Mean | 3.1 | 3.6 | 3.9 | 3.7 | 3.4 | 3.4 | 4.2 |
| Std. Dev. | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.4 |
| % Increase | | 16.1 | 25.8 | 19.4 | 9.7 | 9.7 | 36.1 |
| 300g | | | | | | | |
| Mean | 7.5 | 8.7 | 8.8 | 8.4 | 8.4 | 8.4 | 9.5 |
| Std. Dev. | 0.1 | 0.2 | 0.3 | 0.4 | 0.1 | 0.3 | 0.5 |
| % Increase | | 16.0 | 17.3 | 12.0 | 12.0 | 12.0 | 26.7 |
| **ORALUBE** | | | | | | | |
| 150g | | | | | | | |
| Mean | 3.1 | 3.8 | 4.2 | 4.5 | 4.9 | 4.9 | 3.9 |
| Std. Dev. | 0.1 | 0.0 | 0.1 | 0.1 | 0.3 | 0.3 | 0.2 |
| % Increase | | 22.6 | 35.5 | 45.2 | 58.1 | 58.1 | 25.8 |
| 300g | | | | | | | |
| Mean | 7.5 | 9.3 | 9.5 | 10.1 | 10.0 | 9.9 | 9.9 |
| Std. Dev. | 0.1 | 0.3 | 0.1 | 0.4 | 0.4 | 0.3 | 0.2 |
| % Increase | | 24.0 | 26.7 | 34.7 | 33.3 | 32.0 | 32.0 |
| **APF** | | | | | | | |
| 150g | | | | | | | |
| Mean | 3.1 | 3.8 | 4.2 | 4.5 | 4.9 | 4.9 | 5.5 |
| Std. Dev. | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| % Increase | | 22.6 | 35.5 | 45.2 | 58.1 | 58.1 | 77.4 |
| 300g | | | | | | | |
| Mean | 7.5 | 10.2 | 10.5 | 10.5 | 12.4 | 12.3 | 14.2 |
| Std. Dev. | 0.1 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 |
| % Increase | | 36.0 | 40.0 | 40.0 | 65.3 | 64.0 | 89.3 |
| **GELKAM** | | | | | | | |
| 150g | | | | | | | |
| Mean | 3.1 | 3.5 | 3.5 | 3.6 | 3.7 | 3.4 | 3.8 |
| Std. Dev. | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.4 |
| % Increase | | 12.9 | 12.9 | 16.1 | 19.4 | 9.7 | 22.6 |
| 300g | | | | | | | |
| Mean | 7.5 | 8.4 | 8.5 | 8.1 | 8.5 | 7.9 | 8.5 |
| Std. Dev. | 0.1 | 0.3 | 0.2 | 0.5 | 0.3 | 0.1 | 0.8 |
| % Increase | | 12.0 | 13.3 | 8.0 | 13.3 | 5.3 | 13.3 |

magnitude of force transmitted while held at a fixed strain. This relaxation is ascribed in part to rearrangements within the polymer structure.[7,8] Stress-relaxation is an inherent limitation in maintaining a constant applied force over an extended period of time; the majority of the force loss (50-75%) occurs within the first 24 hours.[9-15] Typically, during the first 24 hours, Alastik chains lose 74% of the applied force compared to 42% for latex elastics.[9,10] Thereafter, force decay continues for both materials but at considerably slower rates. Elastomer plastically deforms by approximately 50% of its original length after 24 hours compared to only 23% for conventional elastics. Some researchers[13] have reported the absence of permanent deformation with elastics compared to elastomeric modules. Others suggested that using initial forces four times greater than the intended load required to move the tooth would compensate for the loss of force after the first day.[9,10]

Pre-stretching elastic chains prior to placement has been recommended to reduce force loss with time (stress relaxation). Pre-stretched elastomeric chains retain 17-25% more force than non-stretched controls after 24 hours.[9,10,14-19] Some researchers, however, have reported that pre-stretching shows no significant difference in stress relaxation over a 3 week period.[20] The optimum amount of pre-stretching is uncertain since some workers have suggested stretching chains three to four times the intended load,[9,10] while others have indicated that pre-stretching modules beyond the elastic limit adversely affects the elastomer and decreases the effective force.[18,19,21] Overall, it appears that pre-stretching of elastomeric modules should be within the range of 50-100% of the initial length.[14,21]

There have been various studies on the effect of environmental conditions on stress relaxation. Some researchers have reported differences between in vivo and in vitro stress relaxation behavior[22] when modules are exposed to different pH media[24] while others found no differences.[9,10] As expected, however, temperature variations were found to affect stress relaxation.[22,23]

In view of the conflicting data on the role of pre-stretching and environment on elastomeric modules, the present study was designed to examine the effects of artificial saliva and topical fluoride treatments on the elastic properties and load relaxation of three brands of orthodontic elastomeric chains.

## Materials and methods

Three orthodontic elastomeric chains with the grey closed loop filament configuration were studied: Ormco Generation II Power Chain (Ormco, Glendora, Calif), Unitek Alastik C1 Modules (heavy) (Unitek/3M, Monrovia, Calif), and TP Orthodontics E-Chain (TP Orthodontics, LaPorte, Ind). The Ormco Generation II and TP E-Chain materials are the latest developments in elastomeric products from their respective manufacturers while Unitek Alastik spool chain C1 is a commonly used elastomeric material. The chains were tested within one week of receipt from the manufacturers and, prior to testing, were kept in air tight plastic bags as originally received from the manufacturer.

The elastomeric chains were immersed in five test media: distilled water, artificial saliva (Oralube, Oral Disease Research Laboratory, Veterans Administration Hospital, Houston, Texas), 0.4% KCl solution, 0.4% $SnF_2$ solution (Gelkam, Scherer Laboratories, Dallas, Texas) and 0.31% acidulated phosphate fluoride (APF, Scherer Laboratories). Unlike the other test media, Gelkam home care fluoride treatment is a gel. The 0.31% acidulated phosphate fluoride, APF, was Part A of the Gelkam FluoroCare topical fluoride rinse used for office fluoride treatment.

All tensile and stress relaxation tests were performed on a Unite-O-Matic FM-20 universal testing machine (United Calibration Corporation, Garden Grove, Calif). The test regimen involved suspending the specimen between a pair of hooks, one attached to the movable cross-head of the tensile tester and the other attached to the fixed base of the machine. The chain was then distracted at a cross-head speed of 50 mm/min until rupture of the chain. The cross-head motion and force required to distract the chain were automatically recorded by the force and displacement transducers of the tensile testing machine. The outputs from the transducers were fed to the internal x-y chart recorder of the instrument. The chart recorder tracings were digitized using a Hypad model DT-114 (Houston Instruments, Houston, Texas), which has an accuracy of 0.1mm, and the data replotted as force versus displacement curves. For each sample, the distractions corresponding to forces of 150g and 300g were determined from the force-displacement curves.

For tensile testing, the chains were carefully removed from the spools without stretching and were trimmed to a strip length of six loops per sample. An extra half loop was allowed at each end to eliminate accidental damage to the chain during removal from the spool. Chains were tested in their as-received state (0 min) and at 4h, 24h and 1, 2, 3 and 4 wk after storage in air and after storage in the test media at 37°±0.5°C in an incubator. Five specimens from each material were tested at each time period for a total of 35 samples for each material.

A stress relaxation study was undertaken to compare the extent of degradation of force delivery for

**Table 2**
**Unitek Alastik C1 Modules**

**Displacement (in mm) to deliver forces of 150g and 300g**

| Time (hours/days) | 0 | 4h | 24h | 7d | 14d | 21d | 28d |
|---|---|---|---|---|---|---|---|
| **AIR** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 4.9 | 4.9 | 5.5 | 5.3 | 5.3 | 5.4 | 5.4 |
| Std. Dev. | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.1 |
| % Increase | | 0.0 | 11.4 | 7.1 | 7.1 | 10.1 | 10.1 |
| **300g** | | | | | | | |
| Mean | 11.3 | 11.4 | 12.1 | 11.9 | 11.2 | 11.8 | 12.2 |
| Std. Dev. | 0.5 | 0.4 | 0.5 | 0.4 | 0.3 | 0.5 | 0.3 |
| % Increase | | 1.3 | 7.6 | 5.9 | -0.9 | 4.5 | 8.5 |
| **WATER** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 4.9 | 6.0 | 6.1 | 6.2 | 5.9 | 5.8 | 5.8 |
| Std. Dev. | 0.1 | 0.3 | 0.0 | 0.3 | 0.4 | 0.3 | 0.2 |
| % Increase | | 21.7 | 23.7 | 24.7 | 19.5 | 17.4 | 17.4 |
| **300g** | | | | | | | |
| Mean | 11.3 | 15.5 | 15.5 | 14.4 | 13.6 | 13.6 | 13.8 |
| Std. Dev. | 0.5 | 0.7 | 0.5 | 0.7 | 1.2 | 0.9 | 0.5 |
| % Increase | | 37.3 | 37.3 | 27.9 | 20.7 | 20.7 | 22.1 |
| **KCL** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 4.9 | 6.0 | 6.1 | 5.9 | 5.7 | 5.7 | 5.8 |
| Std. Dev. | 0.1 | 0.3 | 0.2 | 0.4 | 0.1 | 0.2 | 0.2 |
| % Increase | | 21.5 | 23.7 | 19.5 | 16.4 | 16.4 | 18.5 |
| **300g** | | | | | | | |
| Mean | 11.2 | 16.6 | 14.9 | 14.6 | 13.5 | 14.5 | 13.9 |
| Std. Dev. | 0.5 | 0.6 | 0.1 | 1.1 | 0.8 | 1.0 | 0.5 |
| % Increase | | 48.3 | 32.9 | 30.2 | 20.6 | 29.3 | 24.3 |
| **ORALUBE** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 4.9 | 6.2 | 6.2 | 6.3 | 6.6 | 6.8 | 6.5 |
| Std. Dev. | 0.1 | 0.2 | 0.4 | 0.2 | 0.4 | 0.4 | 0.3 |
| % Increase | | 25.8 | 24.7 | 26.8 | 33.9 | 37.1 | 31.8 |
| **300g** | | | | | | | |
| Mean | 11.3 | 16.7 | 15.7 | 15.4 | 15.6 | 16.4 | 15.9 |
| Std. Dev. | 0.5 | 0.2 | 0.6 | 0.5 | 0.4 | 0.7 | 0.8 |
| % Increase | | 48.1 | 39.5 | 36.4 | 37.9 | 45.5 | 40.5 |
| **APF** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 4.9 | 6.2 | 6.7 | 6.7 | 7.0 | 6.8 | 7.2 |
| Std. Dev. | 0.1 | 143.0 | 0.1 | 0.3 | 0.1 | 0.2 | 0.2 |
| % Increase | | 25.8 | 34.9 | 34.9 | 41.2 | 36.9 | 45.2 |
| **300g** | | | | | | | |
| Mean | 11.3 | 16.7 | 17.2 | 16.4 | 17.6 | 16.6 | 20.5 |
| Std. Dev. | 0.5 | 0.9 | 0.9 | 0.8 | 0.7 | 0.6 | 1.0 |
| % Increase | | 47.7 | 52.2 | 45.5 | 55.9 | 47.3 | 81.5 |
| **GELKAM** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 4.9 | 5.3 | 5.7 | 5.8 | 5.7 | 5.7 | 5.5 |
| Std. Dev. | 0.1 | 0.0 | 0.1 | 0.2 | 0.1 | 0.3 | 0.2 |
| % Increase | | 8.1 | 16.0 | 18.5 | 16.0 | 16.0 | 10.8 |
| **300g** | | | | | | | |
| Mean | 11.3 | 13.2 | 14.2 | 12.9 | 13.0 | 13.1 | 13.0 |
| Std. Dev. | 0.5 | 0.5 | 1.2 | 0.2 | 0.8 | 0.7 | 0.6 |
| % Increase | | 17.1 | 25.5 | 14.3 | 15.0 | 16.0 | 14.9 |

**Table 3**
**TP Orthodontics E-Chain**

**Displacement (in mm) to deliver forces of 150g and 300g**

| Time (hours/days) | 0 | 4h | 24h | 7d | 14d | 21d | 28d |
|---|---|---|---|---|---|---|---|
| **AIR** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 2.1 | 2.1 | 2.3 | 2.3 | 2.3 | 2.1 | 2.1 |
| Std. Dev. | 0.1 | 0.3 | 0.0 | 0.1 | 0.2 | 0.1 | 0.1 |
| % Increase | | -1.0 | 9.0 | 11.4 | 11.4 | 1.4 | -1.0 |
| **300g** | | | | | | | |
| Mean | 4.4 | 4.5 | 5.0 | 4.5 | 4.8 | 4.7 | 4.7 |
| Std. Dev. | 0.4 | 0.4 | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 |
| % Increase | | 2.7 | 13.2 | 2.7 | 9.8 | 6.1 | 6.4 |
| **WATER** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 2.1 | 2.5 | 2.7 | 2.7 | 2.7 | 2.5 | 2.3 |
| Std. Dev. | 0.1 | 0.3 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 |
| % Increase | | 21.0 | 28.6 | 28.6 | 26.2 | 21.0 | 11.4 |
| **300g** | | | | | | | |
| Mean | 4.4 | 5.5 | 6.1 | 5.3 | 5.3 | 5.3 | 5.6 |
| Std. Dev. | 0.4 | 0.3 | 0.5 | 0.3 | 0.3 | 0.2 | 0.4 |
| % Increase | | 24.8 | 38.6 | 21.1 | 21.1 | 20.0 | 27.0 |
| **KCL** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 2.1 | 2.6 | 2.5 | 2.4 | 2.6 | 2.4 | 2.4 |
| Std. Dev. | 0.1 | 0.5 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 |
| % Increase | | 23.3 | 21.0 | 13.8 | 23.3 | 13.8 | 13.8 |
| **300g** | | | | | | | |
| Mean | 4.4 | 5.9 | 5.4 | 5.0 | 5.8 | 5.2 | 5.6 |
| Std. Dev. | 0.4 | 0.6 | 0.9 | 0.5 | 0.3 | 0.3 | 0.6 |
| % Increase | | 35.0 | 23.6 | 13.2 | 31.6 | 17.7 | 27.0 |
| **ORALUBE** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 2.1 | 2.8 | 2.9 | 2.9 | 2.8 | 2.8 | 2.6 |
| Std. Dev. | 0.1 | 0.2 | 0.3 | 0.2 | 0.3 | 0.1 | 0.3 |
| % Increase | | 31.0 | 38.1 | 35.7 | 33.3 | 31.0 | 25.7 |
| **300g** | | | | | | | |
| Mean | 4.4 | 6.2 | 6.4 | 6.2 | 6.2 | 6.0 | 5.8 |
| Std. Dev. | 0.4 | 0.6 | 0.7 | 0.7 | 0.7 | 0.4 | 0.5 |
| % Increase | | 39.8 | 44.3 | 39.8 | 39.8 | 37.3 | 32.7 |
| **APF** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 2.1 | 2.5 | 2.5 | 3.0 | 2.6 | 2.5 | 2.8 |
| Std. Dev. | 0.1 | 0.1 | 0.3 | 0.4 | 0.3 | 0.0 | 0.2 |
| % Increase | | 18.6 | 18.6 | 40.5 | 25.7 | 21.0 | 31.0 |
| **300g** | | | | | | | |
| Mean | 4.4 | 5.5 | 5.8 | 6.0 | 5.5 | 5.7 | 6.5 |
| Std. Dev. | 0.4 | 0.6 | 0.5 | 0.9 | 0.3 | 0.6 | 1.0 |
| % Increase | | 24.8 | 31.6 | 37.3 | 24.5 | 29.3 | 47.7 |
| **GELKAM** | | | | | | | |
| **150g** | | | | | | | |
| Mean | 2.1 | 2.2 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| Std. Dev. | 0.1 | 0.2 | 0.2 | 0.0 | 0.3 | 0.3 | 0.3 |
| % Increase | | 3.8 | 11.4 | 9.0 | 9.0 | 9.0 | 9.0 |
| **300g** | | | | | | | |
| Mean | 4.4 | 4.8 | 5.0 | 4.5 | 4.8 | 4.7 | 4.9 |
| Std. Dev. | 0.4 | 0.4 | 0.5 | 0.2 | 0.5 | 0.3 | 0.2 |
| % Increase | | 8.4 | 13.2 | 2.7 | 9.5 | 6.4 | 10.9 |

each material. It has been suggested that pre-stretching decreases the amount of force degradation; therefore, stress relaxation was studied in both pre-stretched and unstretched chains. To pre-stretch the material, chains were trimmed to a strip length of eight loops per sample (to avoid damage to the first and sixth loops during the stretching procedure) and slowly stretched to 100% of the original length and held for 10 seconds in the stretched position, using a Boley gauge for accuracy. Five more specimens of each material, which were not pre-stretched, were trimmed to a strip length of six loops per sample with an extra half loop on each end. All specimens were stored in air or the test media in an incubator at $37^{o} \pm 0.5^{o}C$ for 24 hours prior to testing.

Tensile testing showed that the chains immersed in APF exhibited the greatest displacement to achieve a given force; storage in distilled water, Oralube and KCl had intermediate effects. Therefore, APF and distilled water were selected as the test media.

Five specimens of each material were pre-stretched 100% of their initial length prior to storing in the test media. The test regimen involved suspending the specimen between a pair of hooks as in the tensile test procedure. The chain was then distracted at a cross-head speed of 50mm/min until an approximate force of 300g was obtained. At this point the crosshead motion was stopped and the chain was held at this distracted length for 36 minutes while the force transducer and internal chart recorder plotted the change in delivered force as a function of time. The plot produced by the internal chart recorder was digitized and the data represented graphically as force versus time. For each sample, forces were determined from the stress relaxation curve at 15 and 30 sec, and at 1, 3 and 30 min and the percentage remaining force at each time period was calculated.

Mean values and their standard deviations were calculated for each set of data and a one-way analysis of variance (ANOVA) was used to compare the data for a given manufacturer's product in the different test media. Those treatments which revealed a significant difference from the control (air) were identified using the Tukey-Kramer HSD (Honestly Significant Difference) test for unpaired data. Statistical significance was set at an a priori $\alpha$ of $p<0.05$. Multivariate analyses were not undertaken since each manufacturer's product was tested independently of the other materials and therefore interactive effects were not sought.

**Results**

Tensile data for the three test materials in air and in the five test media over the four week testing period are summarized in Tables 1-3. In virtually every case there was a progressive increase in the displacement required to produce 150g and 300g under all storage conditions throughout the entire test period (Figures 1-3). The data in Tables 1-3 indicate that during the first 4 hours there was a rapid increase in displacement required to produce the required force followed by a more gradual increase in displacement between 4 hours and 28 days. The data also indicate that the increase in distraction varied with both the elastomer chain and the test medium although, in all cases, the least increase was found for air and the greatest with APF. Only the TP material showed no change ($p>0.05$) in the distraction to achieve a force of 150g after storage in air for 28 days. It should be noted that although there appeared to be large differences between the mean values of distractions for 150g or 300g forces (Tables 1-3) and between the percentage increase in distraction for a given load (Figures 1-3), many of these differences were not statistically significant.

Tensile data for the Ormco elastic chains showed that the distractions to achieve forces of 150g and 300g were greater in all media ($p<0.05$ or 0.01) compared to that in air. Further, the distractions to achieve forces of 150g and 300g were greater ($p<0.05$ or 0.01) for the chains stored in APF and Oralube than for those stored in distilled water, but there were no statistically significant differences ($p>0.05$) between distilled water, KCl and Gelkam for a force of 300g.

The Unitek elastic chain tensile data showed that distractions to achieve forces of 150g and 300g were greater in all media ($p<0.01$) compared to that of chains stored in air, except for those stored in Gelkam where no statistically significant difference was found ($p>0.05$). The distraction required to produce a force of 300g was greater for all media ($p<0.01$) compared to those stored in air. The displacements for forces of 150g and 300g after storage in Oralube and APF were greater than those for storage in distilled water ($p<0.01$) at day 14 and subsequently. Prior to that time, no statistically significant differences were found between the test media ($p>0.05$).

Tensile data for the TP elastic chains indicate that the distraction to achieve a force of 150g was greater ($p<0.01$) only for the chains stored in Oralube compared to those stored in air from the initial time through 7 days of testing. Thereafter, the distraction to achieve a force of 150g was greater for the chains stored in Oralube and APF compared to those

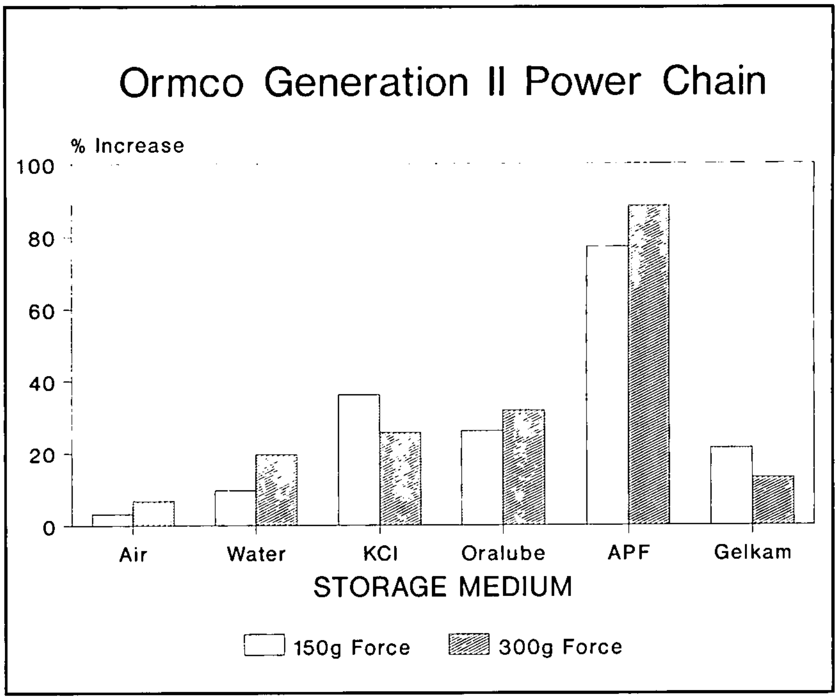


**Figure 1**

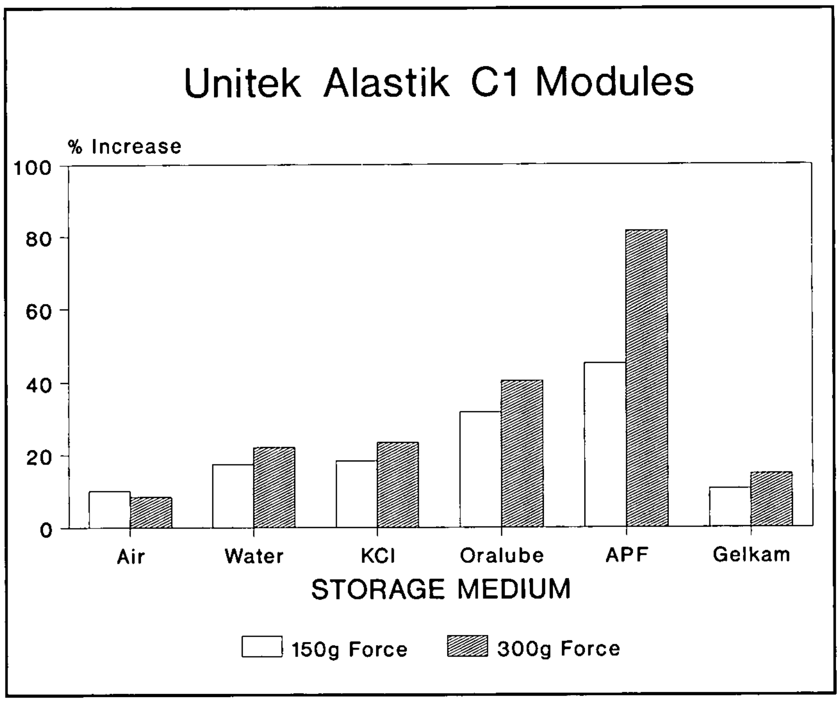


**Figure 2**

**Figure 1**
**Increase in the required distraction, relative to as-received modules, of Ormco Generation II power chain to deliver forces of 150 and 300g after storage in different media for 28 days.**

**Figure 2**
**Increase in the required distraction, relative to as-received modules, of Unitek Alastik C1 modules to deliver forces of 150 and 300g after storage in different media for 28 days.**

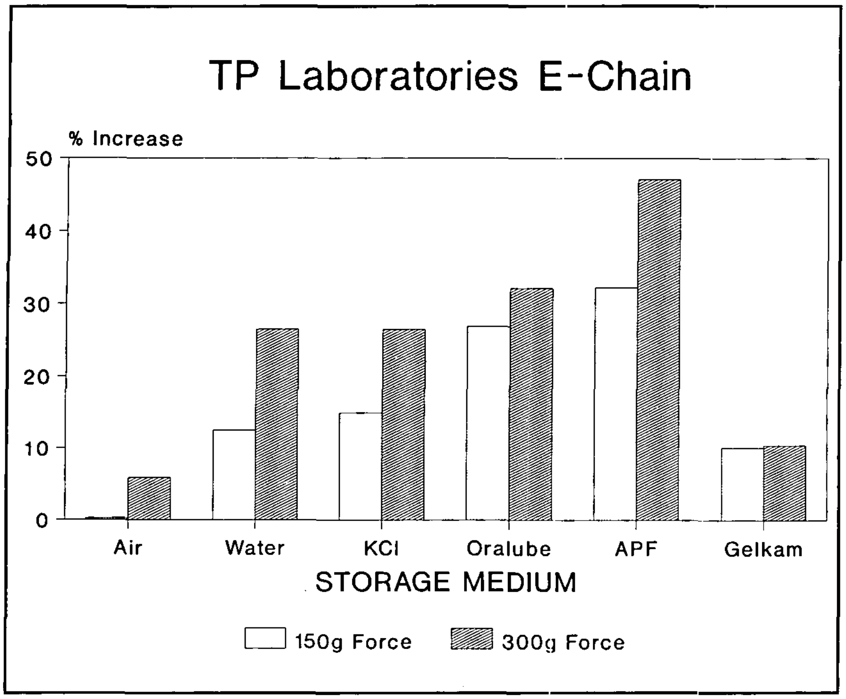


Figure 3

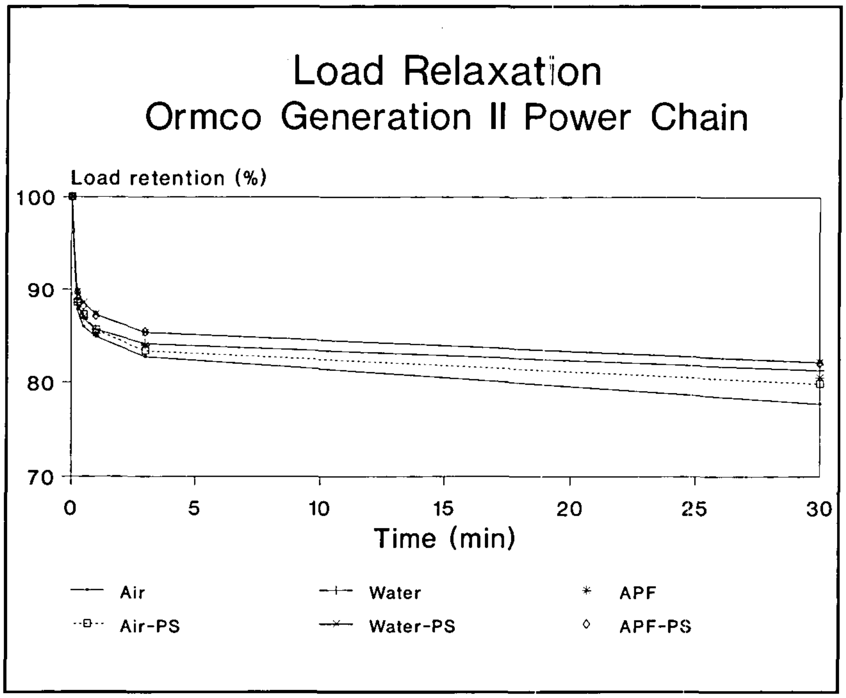


Figure 4

**Figure 3**
**Increase in the required distraction, relative to as-received modules, of TP Laboratories E-chain modules to deliver forces of 150 and 300g after storage in different media for 28 days.**

**Figure 4**
**Percentage retention of a 300g load for Ormco Generation II power chain when exposed to air, distilled water and APF.**

stored in air (p<0.01). There were no differences in the distractions required to achieve 150g after storage in water, Gelkam and KCl (p>0.05). The distraction to achieve a force of 300g was greater (p<0.01) for chains stored in Oralube and APF compared to those stored in air. No statistically significant differences were found in the distractions required to produce 300g between air, distilled water, KCl and Gelkam stored chains(p>0.05).

The load relaxation behavior of the elastomeric chains is shown in Figures 4-6 and the percent load retention at 30 minutes is summarized in Table 4 with statistical analyses summarized in Table 5. The force delivered by each chain decreased throughout the test period with the bulk of load relaxation occurring over 30 minutes with a slower but progressive decrease thereafter to a range of 72-84%. The Ormco power chain retained the highest force levels throughout the test period, Unitek Alastik modules retained the lowest force levels and TP E-Chain was intermediate.

Overall, the load relaxation of both pre-stretched and unstretched modules was less, i.e. the specimens retained higher forces, when the chains were stored in liquid or gel than when they were exposed only to air (p<0.01). No difference (p>0.05) was found in load retention for water or APF storage for any of the unstretched or pre-stretched modules. Pre-stretching had no effect on load relaxation, except for Ormco Power Chain in air, where a significant (p<0.05) difference was found between the pre-stretched and unstretched chains.

## Discussion

The force/displacement curves for the three elastomeric chains differed slightly but the overall shapes were the same. The displacements required to achieve loads of 150g and 300g were greatest for Unitek Alastik C1 modules and least for TP Orthodontics E-Chain, indicating that the latter had a greater stiffness (modulus) than the other two elastomers. All three materials required increased distractions to deliver the same force over time in air and the test media, Figures 1-3. Most of the increased distraction occured within the first 4 hours of loading with a slower increase in required distraction thereafter for up to 28 days, Tables 1-3. Thus, for a given distraction, the force delivered by an elastomer decreased over a period of 28 days with the greatest force loss occurring within 4 hours. These data support previous reports that elastomeric chains tend to loose between 50-75% of their initial force over the first 24 hours of application. However, the relaxation data in Figures 4-6 and Table 4 clearly indicate that there is a very rapid and early load relaxation.

This rapid decrease of load with a fixed module distraction might appear to be advantageous in the clinical setting because the rapid initial reduction of force would minimize the discomfort felt by the patient. However the rapid decrease in force could introduce changes in the patient's anticipated clinical response to the treatment plan. It should be noted, however, that after the first 4 hours, an average increase in distraction of 0.5-2mm was required to produce 150g and 1-5mm was required to produce 300g. The distractions necessary to maintain delivery of 150g and 300g of force continued to increase with time over 28 days. The additional distraction required to produce 300g (2-9mm) is a large increase and the chain would need to be frequently replaced in order to maintain this higher force level. In contrast, the additional distraction to deliver 150g, of the order of 1-2.5mm, was statistically significant but may be barely perceptible in the clinical setting. Further, even at 28 days, the load delivered by an elastomer initially distracted to deliver 150g is still within the clinically preferred range of 75-100g for optimal tooth movement.

This study also showed that exposure to liquid media affected the elastic properties of the elastomeric chains with increases found in the distractions required to deliver 150g and 300g forces, compared to the control (air). The elastomers with lower elastic moduli, Ormco Generation II power chain and Unitek Alastik C1, were affected by storage in all liquid media while the TP elastomer was affected significantly only by storage in Oralube and APF. Further, the effects of the storage media on elastic properties were greater for the Ormco and Unitek elastomers than they were for TP Orthodontics E-chain. Overall, KCl and distilled water had small effects on force degradation while Gelkam had no statistically significant effects on any chain over the entire testing period.

In the load relaxation test, all three brands of elastomeric chain showed a significant loss of force delivery over the testing period, with a force loss (relaxation) of 16-22% over 3 minutes and increasing to 16-28% after 30 minutes. In contrast to tensile data, less load relaxation was observed in chains that were immersed in distilled water and APF than in those exposed only to air. This finding was unexpected and appears to contradict the tensile data, namely that greater load relaxation occurs with distilled water and APF than occurs with air. Further work is clearly necessary to account for these differences. Future efforts will be devoted to investigating the effect of the storage medium on elastic properties of elastomeric modules, particularly their load relaxation behavior.

Pre-stretching the modules appeared to have little effect on load relaxation. Although pre-stretching the modules by 100% of the initial length does not

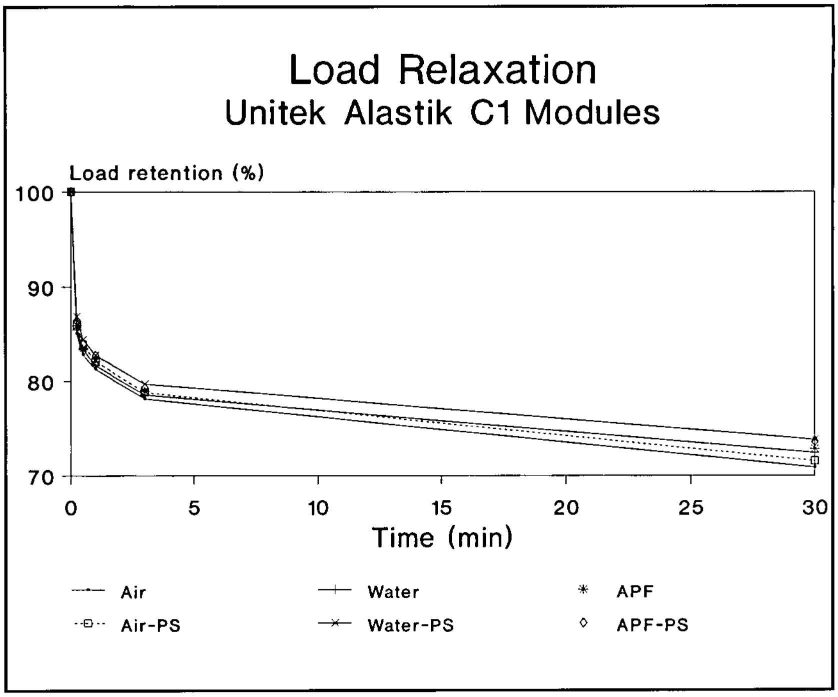


Figure 5

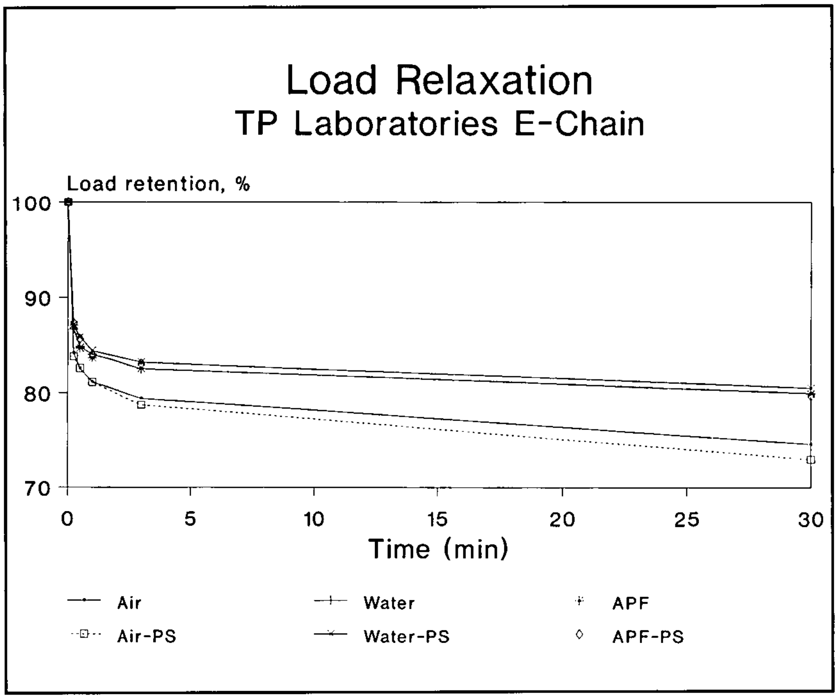


Figure 6

**Figure 5**
**Percentage retention of a 300g load for Unitek Alastik C1 modules when exposed to air, distilled water and APF.**

**Figure 6**
**Percentage retention of a 300g load for TP Orthodontics E-chain when exposed to air, distilled water and APF.**

**Table 4**
**Statistical comparison (Tukey-Kramer)**
**of percentage load retention at 30 min in different media**

| | Pre-stretched vs Unstretched | | | Unstretched | | | Pre-stretched | | |
|---|---|---|---|---|---|---|---|---|---|
| | Air | Water | APF | Air vs water | Air vs APF | Water vs APF | Air vs water | Air vs APF | Water vs APF |
| Ormco | pS | nS | nS | S | S | nS | S | S | nS |
| Unitek | nS | nS | nS | nS | pS | nS | S | pS | nS |
| TP Labs. | nS | nS | nS | S | S | nS | S | S | nS |

nS: p> 0.05; pS: p< 0.05; S: p< 0.01

appear to adversely affect performance, it does not necessarily improve it. Additional work will be undertaken on a wider sample of elastomeric chains to determine the effect of pre-stretching and the optimum amount of pre-stretching.

This article reports the findings of an in vitro study on the properties of elastomeric modules exposed to different storage media under controlled conditions. The in vivo behavior of the modules may differ markedly due to such variables as wide temperature swings, masticatory forces and parafunctional oral behavior. Therefore, although the present findings are a useful guide to the anticipated clinical behavior of the elastomeric modules, the observed clinical behavior may differ; caution must be exercised in extrapolating in vitro findings to in vivo behavior.

## Conclusions

This study has shown that load relaxation occurs with elastomeric modules under all conditions, requiring an increase in distraction to maintain the same load delivery over a period of time. However, the rate of load relaxation was found to vary with the module and its environment, elastomers of lower modulus showing greater effects than higher modulus material. Although the observed load relaxation was statistically significant for chains stored in in air and liquid media, the observed relaxation may be a problem in the clinical situation only when the module is required to deliver high forces, >300g, or if there is prolonged exposure to fluoride media. Pre-stretching appeared to have an overall beneficial effect only for Ormco Generation II power chain.

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**Table 5**
**Load retention (percentage of initial load) for as-received and pre-stretched elastomeric chains after storage for 30 min in different media**

| Storage Medium | Ormco | Unitek | TP Laboratories |
|---|---|---|---|
| Air | 77.71 ±1.30 | 70.89 ±1.62 | 74.63 ±1.42 |
| Water | 84.15 ±1.09 | 72.47 ±0.60 | 80.02 ±0.95 |
| APF | 80.52 ±0.58 | 72.88 ±0.71 | 79.94 ±1.20 |
| Air (pre-stretched) | 79.83 ±1.31 | 71.58 ±1.02 | 73.01 ±1.18 |
| Water (pre-stretched) | 82.18 ±0.81 | 73.87 ±0.44 | 80.54 ±0.92 |
| APF (pre-stretched) | 82.09 ±0.38 | 73.64 ±0.63 | 79.69 ±1.09 |
| F value (4,24df) | 14.80 | 7.93 | 41.08 |

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