PHYSICAL PROPERTIES OF VARIOUS BRANDS OF ELASTOMERIC CHAINS

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Forces needed for orthodontic tooth movement are obtained from various appliances such as orthodontic wires or elastic rubber. Orthodontic elastic rubber is widely used clinically, but permanent deformation and force decay may occur from the environmental changes, time of clinical use and the extent of the stretch, making the prediction of force being applied difficult. The present study examined and compared the changes in residual force between three brands of elastomeric chains (Ormco : Generation II Power Chains ; brand A, RMO : Energy-Chain ; brand B, Unitek : AlastiK ; brand C) under various environmental conditions, amount of initial force, types of elastomer and the rate of extension. The characteristic physical properies of the elastomeric chains were as follows.

1. In all three brands, the residual force ratio was largest when the chains were stored in air, with no difference between water and saliva.
2. In all three brands, after 24 hours, there was no statistical difference in residual force ratio according to the initial force level.
3. In Brand A and B, the presence of filament had no correlation with the residual force ratio. In Brand C force decay was more severe when the chain contained filament.
4. In each brand, rate of extension had no effect on residual force ratio.
5. Brand B showed relatively higher residual force ratio compared to other brands.

Key Words : elastomeric chain, environment, residual force ratio, force decay, stretch

F orces needed for orthodontic tooth movement can be obtained from various appliances such as orthodontic wires or elastic rubber. Orthodontic elastic rubber can be used for closure of extraction space, closure of diastema, correction of midline deviation, general space closure, provision of tooth rotation and anti-rotation, correction of crossbite, forced eruption

and occlusal seating at the finishing stage of fixed appliance therapy[31]. The elastics are classified as band, ring, module, chain or strip types[9], and an appropriate type is chosen according to the range of action, force and patient conditions[1].

Orthodontic elastic materials can be classified either latex rubber or synthetic rubber. Latex rubber is made of naturally extracted rubber and mainly manufactured as band form. It is used in the application of extraoral or intermaxillary force. Synthetic rubber polymers are made of polyurethane, with a few additives to improve strength and resistance to free radicals which can weaken the polymer structure. The manufacturing method

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Table 1. Types and shapes of elastomeric chain

Type / Company	Material	Filament	Color
Ormco (Brand A)	Generation II Power Chains	closed space (no) open space (yes)	clear
RMO (Brand B)	Energy-Chain[TM] Elastics	closed (no) narrow (yes)	clear
Unitek (Brand C)	Alastik[TM] C Modules	CK (no) Cl (yes)	regular clear

Table 2. Contents and conditions of the experiment

Variables / Test	Environment	Filament	Initial force at H0	Rate of extension
1	Air(a)	No	Optimal(O)	Normal(N)
2	Water(w)	No	Optimal	Normal
3	Saliva(s)	No	Optimal	Normal
4	Saliva	No	Heavy(H)	Normal
5	Saliva	Yes(F)	Optimal	Normal
6	Saliva	No	Optimal	Fast(F)
7	Saliva	No	Optimal	Slow(S)

and contents may differ according to manufactureres [11,33,34]. Since its first introduction to an orthodontist in the 60s, synthetic rubber is being used more widely than latex rubber, mainly for the control of tooth rotation and space closure[3,5,9].

What makes the clinical use of these materials possible is its reversible elastic behavior. It is difficult, however, to predict the force being applied since the force from the elastics shows non-linear elongation patterns, and environmental influences, time and stretching may result in permanent deformation and marked force decay[6,7,16].

Two main mechanisms in the force decay of synthetic rubber are elastic stretching and chain slippage. The former is a reversible reaction which occurs when each polymer molecule uncoils and stretches, and the latter is a slippage and permanent deformation of the molecules from the force being applied. Activated elastomeric chain goes through elastic stretching first, then slippage later[22]. Ideally, orthodontic force should decrease or disappear as a result of tooth movement, but a large portion of the force is also lost by the physical degradation of the material itself. Such loss may vary according to the type of the material and manufacturer, and marked loss occurs in the first 24 hours and gradually progresses thereafter down to 20 % - 75 % of the initial force[6,22,31]. For maintaining tissue health, interrupted force is preferred over continuous force, and the loss of initial force may be viewed as beneficial. When the initial force loss is compensated in elastic rubber, however, the force level may be too great, resulting in tissue damage. If the loss

is ignored, on the other hand, the force level may be too low to cause tooth movement, and the treatment time may be extended. It is therefore difficult to obtain just the right amount of initial force and difficult to estimate the residual force[2].

The present study evaluated residual force of three clinically popular brands of elastomeric chains under various environmental conditions, initial force level and types of elastomer, and the rate of extension.

II. MATERIALS & METHODS

1. Materials

Three brands of elastomeric chains, Brand A (Ormco), Brand B (RMO) and Brand C (Unitek), either with or without filament between elastomer units were used (Table 1, Fig 1). Synthetic saliva, freshened every 3 day was used to reproduce oral environment. To obtain consistent amount of extension, an extension device with 1.2mm orthodontic wire embedded parallel within extra-hard die-stone was used. The distance, based on the distance from the center of the labial surface of upper canine to the center of the buccal surface of upper 1st molar, was set at 25 mm (Fig 2). Universal testing machine (Model 6022, Instron Co., USA) was used to measure the time-dependent changes in the residual force (Fig 3) with the cross head speed of 900 mm/min (fast), 300 mm/min (normal) and 50 mm/min (slow). The force level was measured with a 10 N load cell.
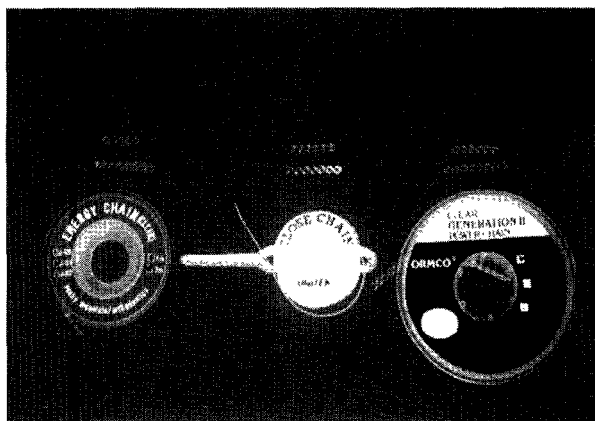
A. Elastomeric chains without filament
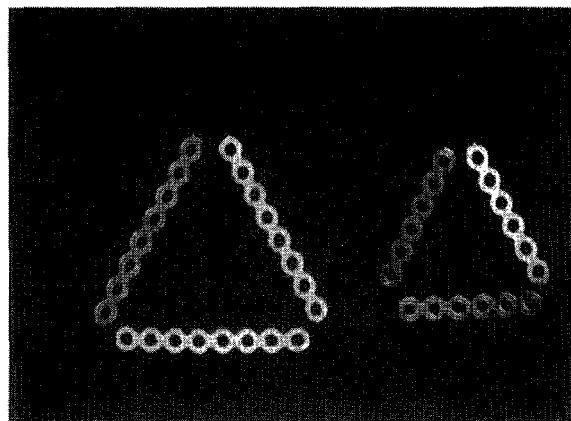
B. 6 or 8 unit modules

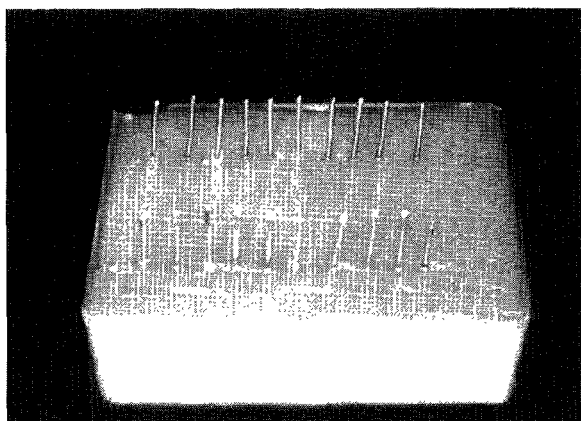**Fig. 1.** Types and shapes of elastomeric chains

Fig. 2. Hard stone die for providing extension of elastomeric chains

2. Methods

Contents and conditions of the experiment were as follows (Table 2). The force level of the elastomer without filament, extended 25mm was defined as optimal between 180 gm ‑ 270 gm for 8 unit module and as heavy between 350 gm ‑ 480 gm for 5 to 6 unit module. The force level of the elastomer with filament was defined as optimal between 196 gm ‑ 287 gm. For each brand, 10 samples were stored in either air under room temperature (a), 36℃ distilled water (w) or 36℃ synthetic saliva(s), and the residual force level were measured: at the initial stage (H0); after 1 hour (H1);
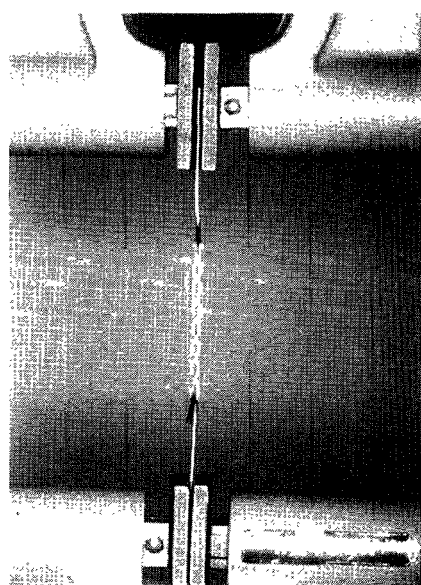
Fig. 3. Specimen mounting on Instron testing machine for the stress testing

12 hours (H12); 24 hours (H24); 1 week (W1); 2 weeks (W2); 3 weeks (W3) and 4 weeks (W4). The ratio of residual force to initial force (H0) was calculated.

Following the above-mentioned process, two brands which showed sound residual force level were chosen, and the residual force of the elastomer without filament stored in synthetic saliva with varying rate of extension was measured.

Table 3. Time-dependent changes in residual force magnitude & ratio for each brand

Brand	Test	Initial force (H0) Mean Force	S.D.	H1 Mean Force Ratio	S.D.	H12 Mean Force Ratio	S.D.	H24 Mean Force Ratio	S.D.	W1 Mean Force Ratio	S.D.	W2 Mean Force Ratio	S.D.	W3 Mean Force Ratio	S.D.	W4 Mean Force Ratio	S.D.
A	1	183.61	4.06	128.32	6.08	117.5	5.87	107.64	4.51	94.17	4.82	89.67	3.98	84.67	4.46	84.40	3.15
		69.90	2.99	63.99	3.41	58.62	2.30	51.29	1.89	48.84	3.04	46.11	3.87	45.97	2.31		
	2	182.31	2.75	111.00	7.09	92.84	5.40	80.73	5.91	69.41	4.05	65.73	4.72	60.91	5.91	61.39	5.60
		60.89	3.71	50.92	2.97	44.28	4.02	38.07	1.60	36.05	2.23	33.41	4.88	33.67	2.89		
	3	181.83	4.73	107.47	5.90	93.99	6.18	83.37	5.23	67.90	4.55	62.07	4.74	58.93	4.87	56.91	5.07
		59.10	2.71	51.69	1.92	45.85	2.48	37.34	1.29	34.14	3.41	32.40	3.31	31.30	4.94		
	4	387.14	5.10	211.27	7.70	187.26	7.30	169.67	9.20	140.88	5.00	130.27	8.60	120.15	5.60	119.83	6.13
		54.57	3.09	48.37	2.69	43.83	2.42	36.39	1.61	33.65	2.79	31.04	3.56	30.95	4.67		
	5	241.81	6.83	148.83	5.44	131.78	6.08	118.19	7.66	97.08	5.38	89.26	0.58	84.44	5.91	83.68	7.18
		61.55	2.18	54.50	1.57	48.88	2.89	40.15	0.85	36.91	2.22	34.92	4.41	34.61	3.27		
	6	180.30	4.51	104.84	6.66	88.92	7.91	79.85	5.56	67.25	7.33	60.17	6.51	56.45	3.80	52.68	7.84
		58.15	3.08	49.32	2.01	44.29	2.41	37.30	1.14	33.37	2.21	31.31	3.00	29.22	3.80		
	7	168.89	3.83	103.86	7.56	88.06	8.45	78.10	9.18	61.85	6.97	54.11	7.93	50.99	0.41	50.19	0.45
		61.50	3.01	52.14	1.66	46.24	2.54	36.62	1.37	32.04	2.64	30.19	2.96	29.72	3.84		
B	1	208.47	11.35	144.70	6.99	131.00	5.01	120.80	4.61	108.54	4.43	101.93	3.31	99.79	2.59	97.20	4.94
		69.41	4.36	62.84	3.90	57.95	3.77	52.07	2.27	48.89	2.29	47.87	4.54	46.63	4.47		
	2	203.46	7.59	126.90	4.32	109.34	4.43	98.43	4.12	88.73	3.64	78.87	5.09	71.35	5.45	67.67	5.10
		62.37	2.91	53.74	3.05	48.38	3.90	43.61	2.18	38.76	3.50	35.07	4.90	33.26	5.03		
	3	207.10	5.16	131.21	6.18	113.82	8.25	100.56	5.74	88.36	5.30	78.22	5.13	71.72	4.71	67.01	4.91
		63.36	2.43	54.96	2.96	48.56	2.99	42.67	2.42	37.77	3.39	34.63	3.77	32.36	5.56		
	4	486.31	6.95	286.53	7.32	243.80	6.25	214.90	7.26	196.46	7.85	178.57	4.64	163.13	5.78	152.35	6.67
		58.92	2.19	50.13	2.38	44.19	2.90	40.40	1.43	36.72	1.90	33.54	4.51	31.33	3.88		
	5	196.60	2.83	127.18	7.20	110.78	4.75	98.12	6.33	85.09	4.78	76.69	3.99	70.89	4.34	65.64	4.86
		64.69	1.83	56.35	2.62	49.91	2.91	43.28	2.29	39.01	4.28	36.06	3.67	33.39	4.51		
	6	203.33	4.80	123.51	8.34	107.88	0.65	98.72	6.84	84.27	7.92	80.95	9.83	74.26	6.64	68.41	6.11
		60.74	2.35	53.06	3.17	48.55	2.74	41.44	1.59	39.81	2.53	36.52	2.57	33.64	5.88		
	7	182.22	2.70	115.31	4.08	101.46	4.81	91.40	8.49	76.14	8.17	72.47	5.69	69.25	6.48	61.84	7.51
		63.28	1.64	55.68	3.04	50.16	2.67	41.78	1.66	39.77	3.07	38.00	4.27	33.94	5.99		
C	1	278.20	1.57	198.14	8.07	179.91	8.59	171.14	5.50	136.15	6.69	122.31	6.06	111.58	6.62	99.43	4.94
		71.22	2.91	64.68	1.49	61.52	1.29	48.94	2.70	43.94	3.10	40.11	2.42	35.74	1.86		
	2	271.51	4.47	142.21	4.23	118.04	7.44	96.80	6.95	77.67	8.50	67.81	7.39	61.58	0.11	51.51	9.93
		52.38	3.22	43.48	2.61	35.65	2.53	28.61	3.35	24.97	2.04	22.67	3.67	18.97	3.77		
	3	269.86	4.48	142.81	3.30	113.97	6.33	93.32	6.76	73.26	8.98	65.29	1.30	61.56	2.03	48.78	0.02
		52.93	2.16	42.23	2.30	34.58	2.40	27.15	3.18	24.19	2.08	22.82	4.55	18.08	3.86		
	4	351.31	7.53	182.97	8.75	150.39	1.29	129.22	1.02	101.09	6.01	93.26	4.89	80.43	9.01	70.87	0.58
		52.10	2.70	42.81	3.35	36.78	3.18	28.78	4.36	26.55	4.41	22.89	5.47	20.19	3.09		
	5	287.86	6.43	120.07	7.82	93.16	5.64	72.50	5.45	53.27	6.86	43.76	4.89	34.89	8.85	26.60	0.86
		41.71	3.10	32.37	2.04	25.21	2.08	18.51	2.57	15.20	1.72	12.12	3.14	9.24	2.49		

3. Statistical analysis

For statistical analysis, the changes in residual force ratio in various environmental conditions, initial force levels, types of elastomer and the rate of extension were obtained, and mean and standard deviation of residual force magnitude and ratio in each time interval were calculated. The ratio of residual force to the initial force
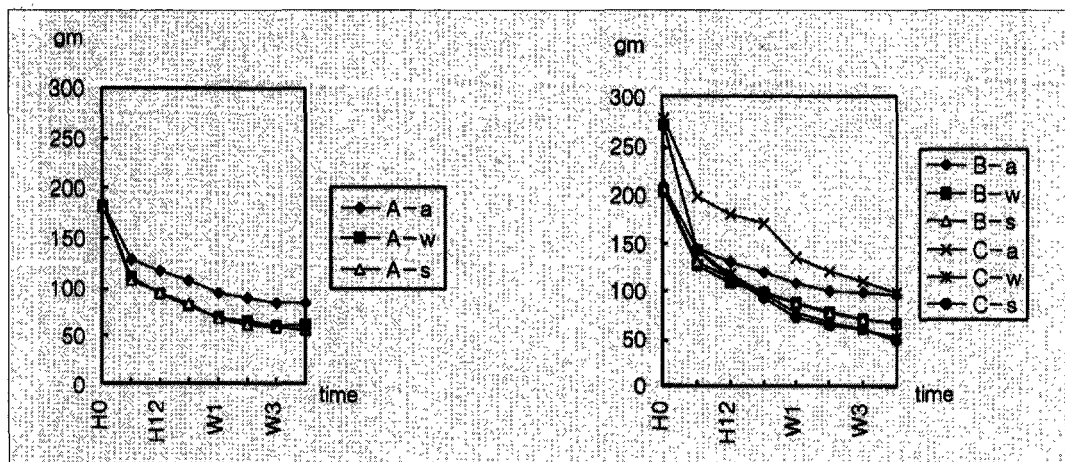
Fig. 4. Changes in residual force magnitude according to environmental condition
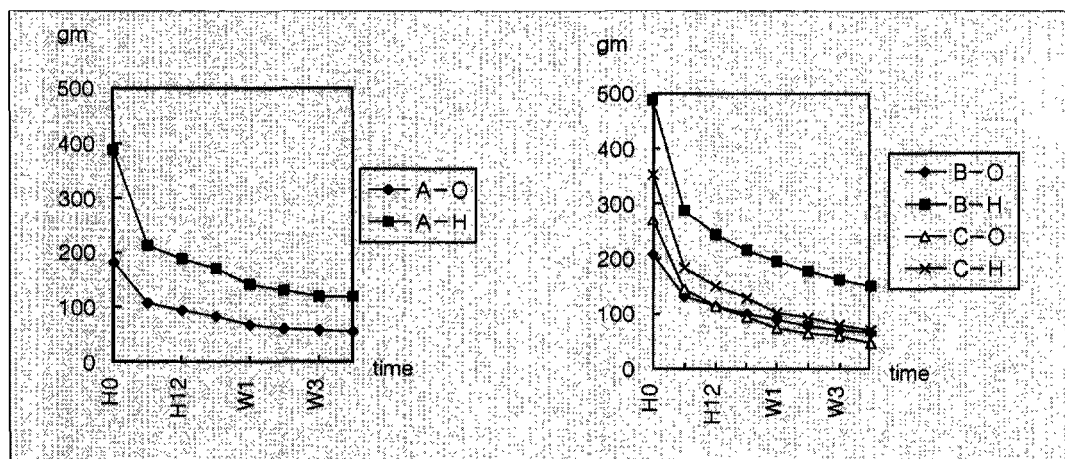brand A;A, brand B;B, brand C;C, air;a, water;w, saliva;s

Fig. 5. Changes in residual force magnitude according to the initial force
brand A;A, brand B;B, brand C;C, optimal;O, heavy;H

was calculated in percentage. Wilcoxon signed rank test was used to evaluate whether the residual force was reduced significantly between the time intervals. The residual force ratio for each brand under various environmental conditions (Kruskal – Wallis test), initial force levels (Wilcoxon rank sum test), types of elastomer (Wilcoxon rank sum test) and the rate of extension (Kruskal – Wallis test) was analyzed. When Kruskal – Wallis test indicated statistical significance, the data were ranked and Tukey's Studentized Range test was used to analyze the significant difference

between the groups.

III. RESULTS

The residual force magnitude and ratio were as follows (Table 3).

1. Time-dependent changes in residual force

The residual force ratio measured under the conditions of Test 3 showed time-dependent reduction
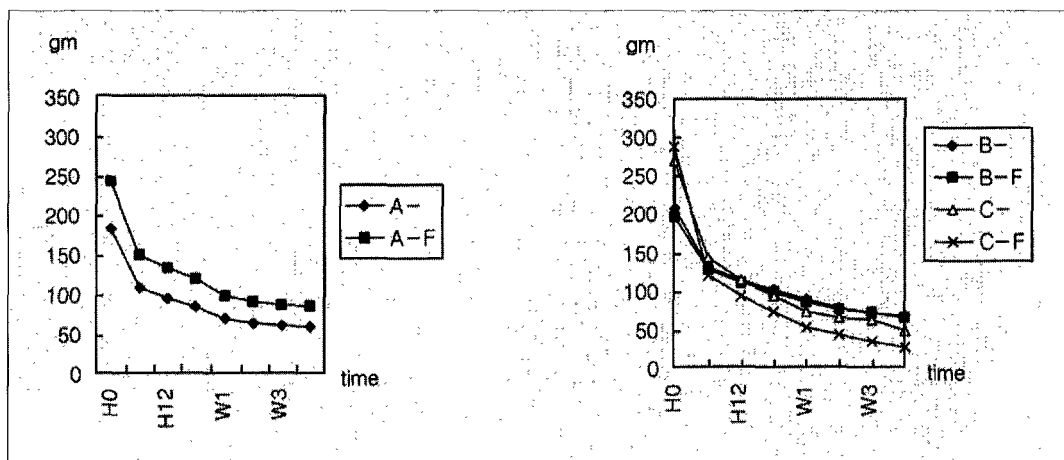
Fig. 6. Changes in residual force magnitude according to the type of the chains brand A:A, brand B:B, brand C:C, F:with filament
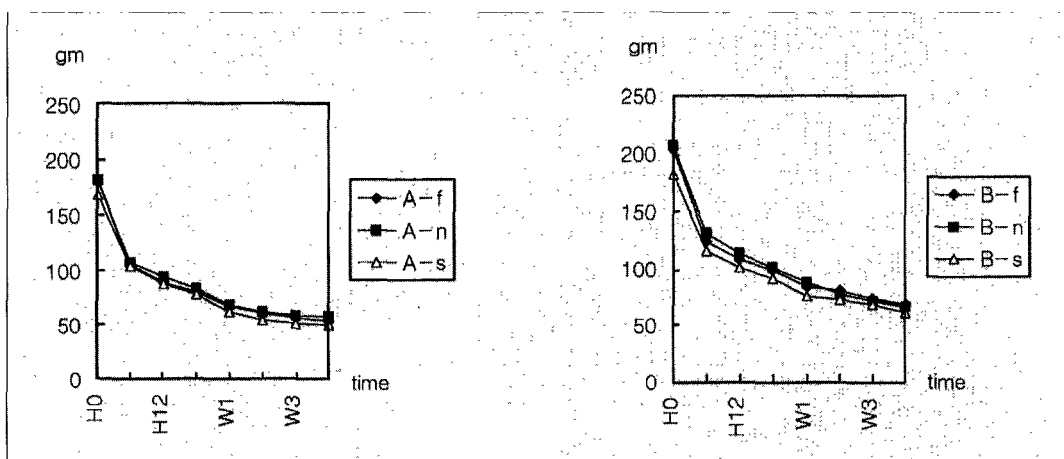

Fig. 7. Changes in residual force magnitude according to the rate of extension A:brand A, B:brand B, C:brand C, F:Fast, N:Normal, S:Slow

in all three brands (Table 4).

2. Changes in residual force according to environmental condition

The residual force ratio measured under the conditions of Test 1, 2 and 3 showed that the chains stored in air had the smallest force decay, with no significant difference for water and saliva (Table 5). Brand C stored in air showed largest force decay after W1. Brand A and B in water and saliva showed larger

residual force ratio than Brand C (Table 6). Changes in residual force magnitude according to environment were shown in figure 4.

3. Changes in residual force according to initial force level

When the initial force was varied either optimal or heavy (Test 3, 4), the residual force ratio showed statistically significant difference for Brand A at H1, H12 and H24 and Brand B at H1 and H12. But Brand

Table 4. Time-dependent decrease in residual force ratio under the conditions of Test 3

Brand \ Time	H1 vs. H0	H12 vs. H1	H24 vs. H12	W1 vs. H24	W2 vs. W1	W3 vs. W2	W4 vs. W3
A	***	***	***	***	***	***	***
B	***	***	***	***	***	***	***
C	***	***	***	***	***	***	***

*** ; P < 0.001

Table 5. Residual force ratio according to environment, initial force magnitude, type of the chain and rate of extension

Variables	Environment			Initial force magnitude			Filament			Rate of extension	
Brand \ Time	A	B	C	A	B	C	A	B	C	A	B
H1	***a-ws	***a-ws	***a-ws	**	**				***		
H12	***a-ws	***a-ws	***a-ws	**	*				***		
H24	***a-ws	***a-ws	***a-ws	*					***		
W1	***a-ws	***a-ws	***a-ws						***		
W2	***a-ws	***a-ws	***a-ws						***		
W3	***a-ws	***a-ws	***a-ws						***		
W4	***a-ws	***a-ws	***a-ws						***		

* ; P < 0.05, ** ; P < 0.01, *** ; P < 0.001
air ; a, water ; w, saliva ; s

Table 6. Residual force ratio according to environment, initial force magnitude, type of the chain and rate of extension

Variables	Environment			Initial force magnitude		Filament		Rate of extension	
Type \ Time	Air	Water	Saliva	Optimal	Heavy	No	Yes	Fast	Slow
H1	*C-AB	***AB-C	***B-A-C	***B-A-C	***AB-C	***B-A-C	***AB-C		
H12		***AB-C	***AB-C	***AB-C	***AB-C	***AB-C	***AB-C		
H24	***C-AB	***AB-C	***AB-C	***AB-C	***AB-C	***AB-C	***AB-C	*	
W1	***AB-C	***B-A-C	***AB-C	***AB-C	**B-A-C	***AB-C	***AB-C	*	
W2	***AB-C	***AB-C	***AB-C	***AB-C	***B-A-C	***AB-C	***AB-C	**	**
W3	***AB-C	***AB-C	***AB-C	***AB-C	***B-A-C	***AB-C	***AB-C	**	**
W4	***AB-C	***AB-C	***AB-C	***AB-C	***AB-C	***AB-C	***AB-C	***	

*; P < 0.05, ** ; P < 0.01, *** ; P < 0.001
Ormco ; A. RMO ; B. Unitek ; C

Table 7. Residual force ratio under various environmental conditions in previous studies

| Company	ORMCO			RMO		Unitek			
Authors	De Genova[16] et al.	Wong[33]	Brantley[16] et al.	Killiany & Duplessis[28]	De Genova[16] et al.	Ash & Nikoll[3]	Brantley[16] et al.	Wong[33]	Young & Sandrik[34]
H0	240 gm	340 gm	374 gm	329.8 gm	289 gm	630 gm	423 gm	340 gm	90 gm
H1		54.8 %			71.2 %	52 %	49.2 %		63.4 %
H24		50 %	43.8 %	77.3 %	62.8 %	39 %	34.8 %	27 %	43.6 %
1w		37 %	38.5 %	72.1 %	57.9 %	34 %	29.6 %	20 %	
2w			35.3 %	71 %		30 %	26.7 %		
3w	41.3 %	27 %	35.0 %	67.4 %	56 %	25 %		21 %	
4w				65.8 %					21 %
Order name	Power chain II 4 unit	Power Chain II	Power Chain II	Energy-Chain closed	Energy-Chain 4unit	AlastiK CK	AlastiK C-spool chain	AlastiK C2	AlastiK CK (closed)
Environment	37 °C saliva thermal cycling	37 °C water	37 °C water	37 °C saliva	37 °C saliva thermal cycling	37 °C in vivo	37 °C water	37 °C water	37 °C water
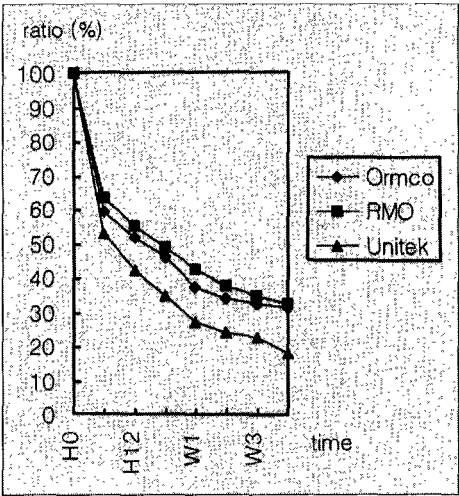
Fig. 8. Changes in residual force ratio in saliva
A:brand A, B:brand B, C:brand C.

C showed no significant difference (Table 5). Residual force ratio under heavy force after W1 was largest in Brand B followed by Brand A and C, with relatively large force decay in Brand C (Table 6). Changes in residual force according to initial force level were shown in figure 5.

4. Changes in residual force according to the type of elastomeric chain

In various types of elastomeric chains under the conditions of Test 3 and 5, residual force ratio for Brand C showed significant difference between the chains with filament and chains without filament. Brand A and B showed no significant difference (Table 5). Among the filament type, Brand A and B showed larger residual force ratio than Brand C (Table 6). Changes in residual force according to the type of elastomer were shown in figure 6.

5. Changes in residual force according to the rate of extension

With various rate of extension of elastomeric chains under the conditions of Test 3, 6 and 7, no difference in residual force ratio was noted in Brand A and B (Table 5). Under rapid extension, Brand B showed lager residual force ratio after H24 with a statistical significance. Under slow extension, Brand B showed larger residual force ratio at W2 and W3 than Brand A (Table 6). Changes in residual force according to the rate of extension were shown in figure 7.

IV. DISCUSSION

An ideal force delivery system requires optimal tooth moving forces to elicit the desired effect, comfortable and hygienic environment to the patient, minimal operator manipulation and chair time, minimal patient cooperation and economical cost[5]. Various methods and materials (TMA loop spring, Ni-Ti coil spring, magnetic, etc.) have been introduced to offer optimal orthodontic force, but none of those materials completely satisfy the above requirements[4,12,24]. The elastic thread of the past can be adjusted for minute changes in orthodontic force, but it is not widely used today due to hygienic problems[29]. But the elastomeric chains are cost-effective, relatively hygienic, easily manipulated, require little patient cooperation and result in clinical tooth movement identical to that of elastic threads[2,9].

As for the optimal force for tooth movement, Storey & Smith[30] and Reitan[27] reported that 100 gm - 250 gm of force were optimal for canine movement, while Begg[10] reported 300 gm and Young & Sandrik[34] reported 180 gm to be appropriate for the same movement. Hixon et al.[20] suggested that high force up to 1000 gm resulted in more rapid tooth movement. Boester & Johsoton[13] showed that the tooth movement was slower when the initial force of 55 gm rather than 300 gm was used while the rate of movement was not significantly different when the initial force was 140 gm, 225 gm or 310 gm.

The optimal force may be different according to the type of tooth movement, but when the elastomeric chain was used for canine retraction, 150 gm - 300 gm of force was used clinically. The present study also defined the force similar in magnitude as optimal force[1,2].

1. The effect of environment

In the present study, all three brands showed reduction of residual force until Week 4 under every environmental condition tested (Table 4). After 1 hour, the force decay was 41 % - 47 %, and after 24 hours, the force loss was 55 % - 65 % (Table 3, Fig 8), making it difficult to decide the magnitude of initial force.

Ash & Nikolai reported that force decay was smallest in the first 30 minutes after extension when the elastomeric chain was in air[8]. Ash & Nikolai, Andreasen and Bishara and Hershey & Reynolds showed no difference in force decay when the chains were stored either in water or saliva[6,7,8,19]. Andreasen & Bishara, Wong, and Ash & Nikolai suggested that the force decay was greater in vivo than in vitro[6,7,8,33]. Comparing the brands under the same conditions, Wong and Sonis et al. showed that Power Chain had smaller force decay than AlastiK, and De Genova et al. suggested that Energy Chain showed greater residual force than Power Chain[15,29,33].

In all three brands, storage in air resulted in the greatest residual force ratio, with little difference between water and saliva (Table 3 and 5). Under the identical condition, Brand C showed smallest residual force ratio (Table 3 and 6)[9,29]. The residual force ratio of Brand A was similar to the ratio in Brantley's report which had similar test conditions as Test 4, but lower than the residual force ratio of 41.3% after 3 weeks in De Genova's study. Unlike the report by Killiany & Duplessis (67.4%) and De Genova et al. (56%) which showed large residual force ratio after 3 weeks for Brand B, the present study showed much lower ratio of 35 %. Brand C in water showed greater residual force ratio than that reported by Wong, and in saliva, the ratio was similar to that reported by Brantley et al.(Table 7).

Studies on the force decay of elastomeric chains show that the decay in vivo may be greater than that in vitro, due to additional deformation from orthodontic activation, mastication and toothbrushing. Chemical influence of free ions and enzymes in saliva as well as temperature changes in the mouth may also become influencing factors[6,7,16,21]. Unique salivary characteristics, diet patterns and oral hygiene status may also make the difference.

2. The effect of initial force

Hershey & Reynolds and Parrie & Spence stated that initial force magnitude and force decay were not correlated[19,26] and Kovatch et al. and De Genova et al. reported that force decay was greater when the initial force was high[15,23]. Young & Sandrik showed that force

decay was smaller when lower force of 90 gm was used rather than heavy force[34].

In the present study, when the magnitude was varied either heavy or optimal, the force decay was greater when heavy initial force was used for Brand A until H24 and for Brand B until H12. The residual force ratio, however, showed no difference after 24 hours for both Brand A and B (Table 5). The residual force magnitude after heavy initial force was reduced to optimal level after H1 and maintained at 120gm between W2 and W4 in Brand A. In Brand B, the force was maintained at 214.9 gm until H24, and at 150 gm until W4 indicating a high force level even after a force decay (Table 3 and 5).

For elastomeric chains, force decay of 70 % - 80 % may occur after 4 weeks of extension. If over-extension is used to compensate for the force decay, undermining resorption from capillary ischemia may occur[6,7]. To compensate for such physical characteristics, prestretching, which applies heavy initial force so that the chain can be used with optimal force, may be recommended.

3. The effect of the configuration

Elastomeric chains are made either through die-punching from extrude strips or through injection molding[21]. The configuration of the chain, namely closed loop, short filament or long filament appears to affect the behavior of elastomeric chains[31,32]. Rock et al. compared 13 brands of elastomeric chains after stretching them 100 % in air and reported that all brands excluding AlastiK by Unitek showed 403 gm to 625 gm of higher initial force level[28]. Hershey and Reynolds showed that, although some difference in force decay existed according to the configuration of the elastomeric chains, there was no clinically significant difference in residual force after 24 hours and 4 weeks[19]. It can be generally stated that the longer filament chains will deliver a lower initial force at the same extension and exhibit a greater rate of force decay under load than the closed loop chain[9].

The initial force is greater in Brand A and C with filament because the number of unit was adjusted to

observe the force changes close to optimal rather than extending the identical length of chain with identical rate. As for the changes in residual force ratio according to the presence of filament, Brand C showed greater force decay when filament was present, while Brand A and B did not show such difference (Table 5). We persume, therefore, that the difference in force decay according to the differences in the type of elastomeric chain is minimal.

4. The effect of the rate of extension

Kovatch et al. reported that the initial load decay was more rapid for both faster extension and higher load[23]. Therefore, slow extension was recommended for enhanced force decay characteristics and maintenance of initial orthodontic force. But it is not known how long the difference in force decay according to the extension rate is maintained. And also, considering the fact that the clinical interval of exchange for elastomeric chain is 3 - 4 weeks, the observation period seems rather short.

In the present study, clinically applied rate of 300 mm/min as well as 50 mm/min and 900 mm/min were used with longer observation period. There was no significant difference in force decay between the three groups (Table 5). Comparing Brand A and B under higher rate of extension, Brand B showed higher residual force ratio after the first day, and under the lower rate of extension Brand B also showed greater residual force ratio at W3 and W4 (Table 6).

The chains used in the present study are selected not based on the physical performance but based on their clinical popularity. Since it is difficult to control the manufacturing date, effective date and storage conditions, the possibility of physical degradation from those factors cannot be ruled out[5]. Furthermore, some loss of elastic force may be expected from the friction between the arch wire and the bracket[17,25]. Comparing the results of the present study with those of previous studies (in vitro), Energy-Chain by RMO and Power Chain by Ormco have showed comparatively less force decay than AlastiK by Unitek, but reports have shown no difference in the actual clinical tooth movement[13].

For maintaining consistent orthodontic force for longer period of time, improvements in physical properties and manufacturing may be required, with more studies on the effect of prestretching of elastomeric chains.

V. CONCLUSION

Forces needed for orthodontic tooth movement are obtained from various appliances such as orthodontic wires or elastic rubber. Orthodontic elastic rubber is widely used clinically, but permanent deformation and force decay may occur from the environmental changes, time of clinical use and the extent of the stretch, making the prediction of force being applied difficult. The present study examined and compared the changes in residual force between three brands of elastomeric chains (Ormco : Generation II Power Chains ; brand A, RMO : Energy-Chain ; brand B, Unitek : AlastiK ; brand C) under various environmental conditions, amount of initial force, types of elastomer and the rate of extension. The characteristic physical properies of the elastomeric chains were as follows.

1. In all three brands, the residual force ratio was largest when the chains were stored in air, with no difference between water and saliva.
2. In all three brands, after 24 hours, there was no statistical difference in residual force ratio according to the initial force level.
3. In Brand A and B, the presence of filament had no correlation with the residual force ratio. In Brand C force decay was more severe when the chain contained filament.
4. In each brand, rate of extension had no effect on residual force ratio.
5. Brand B showed relatively higher residual force ratio compared to other brands.

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국문초록

수종의 합성 고무탄성재의 성질에 관한 연구

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교정적인 치아이동에 필요한 힘들은 orthodontic wire나 여러 가지 elastic rubber 등으로 얻을 수 있다. 이중 교정용 elastic rubber는 환경 변화, 시간 경과, 신장(stretch) 정도에 따라 영구 변형과 힘의 소실(force decay)이 다양하게 나타나므로 적용된 힘을 예측하기 힘든 단점이 있다. 본 연구에서는 임상에서 널리 사용되는 3가지 종류 (Ormco : Generation II Power Chains ; brand A, RMO : Energy-Chain ; brand B, Unitek : AlastiK ; brand C)의 교정용 합성 고무탄성재를 실험 환경, 초기 힘의 크기, 고무탄성재의 형태 그리고 신장속도를 달리한 뒤 시간에 따른 잔존 힘의 변화를 비교하였으며, 종류에 따른 특징적인 물리적 성질에 대하여 다음과 같은 결론을 얻었다.

1. 세 종류 모두에서 상온의 공기에 보관된 경우 잔존 힘의 비율이 가장 컸으며 물과 타액 간에는 차이가 없었다.
2. 세 종류 모두에서 24시간 이후로는 초기 힘의 크기에 따른 잔존 힘의 비율에 차이가 없었다.
3. A, B는 filament 유무에 따른 잔존 힘의 비율에 차이가 없었으나 C에서는 filament가 있는 경우 힘의 소실이 더 많았다.
4. 신장속도를 달리하여도 잔존 힘의 비율에는 큰 차이가 없었다.
5. B는 각각의 실험조건에서 A, C보다 상대적으로 잔존 힘의 비율이 높았다.

색인 단어 : 합성 고무탄성재, 환경, 힘의 소실, 잔존 힘의 비율, 신장속도