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Force Decay Associated With Coloured Elastomeric Chains; an Ex Vivo Investigation

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Abstract: **There are many studies that have investigated the force decay associated with orthodontic synthetic elastomeric chains; however few have compared different colours from different suppliers.**

Aim: To compare the force loss of 3 different coloured elastomeric chains from 3 suppliers.

Method: Three different coloured elastomeric chains; clear, grey, and blue from 3 suppliers; (3M, TP, and GAC (DENTSPLY)) were tested using Instron Tensile Testing Machine. Records of residual force taken; initially, 1 h, 24 h, 7 days, and 28 days.

Findings: Blue had the highest force decay in all the three brands. TP was the only material in which all colours were significantly different. Clear in both 3M and GAC perform better than grey, but grey was superior to clear in TP. All brands have different force decay; TP (grey then clear) gave the highest and the most constant force for the tested period, followed by 3M, and lastly GAC. when comparing the force decay after 7 days, TP (grey and clear) lost 40%-50% of their force and continued to retain it until the end of 28 days, where as 3M, GAC, and TP blue had lost 50%-75% of their force after 7 days, and only retained 13%-32% of their initial force at the end of 28 days.

Conclusions: Different colours have different force decay. The blue colour had the lowest residual force. TP E-chain (grey & clear) maintained the force required for tooth movement for the whole test period, while 3M and GAC fail to deliver the minimum required force after 24 h, and 1 h respectively.

Keywords: **Vivo Investigation, TP E-Chain, Different Force Decay**.

1. INTRODUCTION

Elastomeric chain have many applications in orthodontics, these include space closure, rotational correction and canine retraction (De Genova et al., 1985).There are many studies trying to explore the optimum force required for tooth movements but there is no conclusive evidence. Schwarz (1932) defined the optimum orthodontic force as 28 g/cm^2 of root surface. It is been suggested that clinicians use forces between 115 and 310 g for tooth movement (Chung et al., 1989). Ren et al. (2003) in their systematic review of the literature, performed a meta- analysis to quantify force needed for tooth movement, but as large variation in data from the literature exist (12 animal studies and 12 human studies), they concluded no evidence to allow quantification of optimum orthodontic force needed for tooth movement.

2. CLINICAL OBSERVATIONS

In 1893 the use of natural rubber as a means of applying intermaxillary traction was introduced at the Columbia Dental Congress (Calvin, 1893). It was not until the 1960s that natural and synthetic elastomeric products found wider use in orthodontics to provide force to correct rotations, intermaxillary and extra-oral traction, arch wire ligation and space closure. It has been suggested using edgewise appliance, that canine retraction required a force of 150 g compared to molar retraction: which required 300 g (Storey and Smith, 1952). They also noted that below 150 g, canine did not move significantly. But this is variable between individual patients (Boester and Johnston, 1974; Hixon et al., 1970). Others came to a conclusion that the optimal force required for canine retraction is in the range of 100-200 g. Another 125-250 g is needed to overcome the frictional forces within the bracket slots themselves, before teeth can move along the arch wires (Quinn and Yoshikawa, 1985).

Another important aspect influencing tooth movement is the duration of the applied force and not just the magnitude, this is because bone remodelling during tooth movement, will only take place provided optimum force is applied for a given period of time (Proffit, 1978). That is why any materials used in moving teeth should have the optimum magnitude of force and be of sufficient duration to achieve tooth movement without damage to the root and the periodontal ligament (Brezniak and Wasserstein, 2002).

3. TYPES OF ELASTICS

Elastics are either natural or synthetic forms of rubber. Elastomeric modules are polyurethanes, which is any polymer that contains the urethane linkage whose exact composition is a commercial secret (Taloumis et al., 1997).

Natural rubber:

Latex, a naturally occurring rubber (Cis 1,4-polyisoprene polymer) is obtained from the rubber tree (*Hevea brasiliensis*) and can be formed into loop elastics or thread for clinical use, especially for extra-oral or intermaxillary force delivery (Kim et al., 2005).

Synthetic elastomers:

Synthetic orthodontic elastics were introduced as an alternative to natural latex elastics and became popular, to enhance physical properties. Synthetic rubber is made of polyurethane with additives to improve both strength and resistance to the action of free radicals that can weaken the polymer structure. It is composed of multiple units (monomers) linked together. When comparing the synthetic elastomer with the natural elastomer, the former retained more force compared to latex when stretched (Wong, 1976).

Polyurethane:

Synthetic elastics used in orthodontics are of the polyurethane group, produced by step- polymerisation of a polyether or polyester glycol into poly-(ether)-urethane or poly- (ester)-urethane (Billmeyer, 1984). These are processed by die-cut stamping or injection moulding for clinical use as thread, modules, chain or links. Of the available products there is much variation in the morphology, colour, dimensions and additives used, and precise details are often proprietary knowledge. The biggest drawback of these materials is force decay (Bousquet et al., 2006).

Chemical structure of polyurethane:

Addition polymerization of a diisocyanate (whose molecules contain two –NCO groups) and a dialcohol (two –OH groups). The polymer chain is linked by urethane groups (–O–CO–NH–). The –NH– portion of the urethane group can react similarly to an –OH group, producing cross-linking between polymer chains (Billmeyer, 1984).

Thermoplastic elastomers (TPE):

They are usually a mix of plastic and rubber, this combination gives the material both thermoplastic and elastomeric properties. Elastomers are mostly thermo-set (irreversible), and with a stronger cross-linking covalent bond, but the thermoplastic (can be remelted and remoulded), and are easily used like in injection moulding, and have a weaker dipole or hydrogen bond (Billmeyer, 1984).

Colours and pigments:

A pigment is a material that changes the colour of light it reflects as a result of selective colour absorption. They are widely used for colouring paint, ink, plastic, cosmetics, food and other material. It is the manufacturing variations with unique chemicals and formulas that cause a large variation in consistency and quality of the final product.

In testing different coloured ligatures (Ormolast) using tensile strength, (Dowling et al., 1998) concluded that clear ligatures had the lowest tensile strength compared to grey and orange ligatures.

4. EVALUATION OF DIFFERENT METHODS OF TESTING

Different methods are described in the literature for testing the mechanical properties of elastomeric modules including force decay, tensile strength, toughness, permanent elongation, glass transition temperature (Tg), cycled temperature versus continuous, or comparison with coils. But due to lack of standardization, comparison seems difficult to be attained. Up to date, very few Randomised Clinical Trials are conducted on coloured elastomeric modules available, Appendix 2.

Tensile strength:

One way of testing the physical property of orthodontic elastomeric modules is tensile strength, which can be defined as the maximal stress a structure can withstand before either fracture or rupture (Eliades, 2004). Another method is to use the extension to tensile strength; this property provides an indirect measure of 'toughness', which is either the peak force prior to breaking or the energy required to fracture a material. Wong (1976) compared latex with synthetic elastomers using a fracture test and showed that the latter is superior in retaining strength. He also showed that synthetic elastomers loose up to 73% of it's initial force during the first day, but force decay continued at a slower rate during the rest of the 21 day observation period. Comparing initial tensile properties of elastomeric chains and after exposure to oral environment for 24 h. Eliades et al. (2004). found that with respect to tensile strength and toughness; both have performed similarly.

Permanent elongation:

All elastomeric modules will undergo permanent elongation when subjected to sufficient load. The range is influenced by the rate and duration of loading and by the environmental conditions (Rock et al., 1985; Stevenson and Kusy, 1994). When stretched, a portion of the work elongation is expressed as heat. Also there is molecular re-orientation resulting in permanent deformation. If this happens early (1-24 h), this gives an indication of poor performance of the elastomers to move teeth. Different loadings have been tested ranging from 90-450 g; this also made it difficult to compare previous work. Different appartus with different loadings were used, examples include: Correx gauge, Instron machine, Carpo gauge, digital force gauge, and others (hydraulic, or electrical motors).

Glass transition temperature (Tg):

It is the temperature at which the solid polymer transforms from a rigid glassy state to a flexible rubbery state; difference in pigments may give different Tg values. Renick et al. (2004) using scanning calorimetry determined by the Tg values comparing initial and after clinical use three different colours from three different suppliers; They concluded that in two companies Ormco (Glendora, Calif) and Rocky Mountain Orthodontics (RMO) had similar clinical performance regardless of the colours, but not for G&H (Greenwood, Ind). The disadvantage of this study is that comparing Tg to force decay is not relevant.

Environmental factors

It is well documented that environmental conditions adversely affect the mechanical properties of elastomers.

Wet versus dry:

Wet environments have an adverse effect on elastomers, as they absorb liquid, changing the physical properties of the material, eventually leading to degradation. Baty et al. (1994), investigated four different coloured chains from three different manufacturers and compared the force delivery of these samples in dry versus wet environment; showed that the wet samples delivered less force compared to dry samples, this further proof the work of Wong (1976). All chains showed an increase in dimensional measurements after one week, with a little change thereafter.

Temperature & pH:

The oral environment is subjected to varing temperature and pH during the day. The effect of this along with other variables such as type of foods and drinks taken will have an adverse effect on the behaviour of elastomeric modules (Bousquet et al., 2006). Work by Nattrass et al. (1998) in studying the effect of temperature, acidic media (Coke) and the use of turmeric on elastomeric chains, showed that tested specimens lost more of their initial loading compared to untested dry samples.

Constant versus thermo-cycled:

In an ex vivo study on force degradation using three commercially available elastomeric products (Ormco Power chain II, Rockey Mountain Energy Chain, and TP Elast-O Chain) thermo-cycled samples showed less force decay over a 21 day period compared to samples stored at a constant 37^{o} C (De Genova et al., 1985). Also different testing temperatures where used by different investigators ranging from 22^{o} C in air to 37^{o} C in liquid medium.

5. TYPE OF MATERIALS

Latex versus synthetic elastomers:

In studying the force decay Wong (1976) compared latex with synthetic elastomers using fracture tests. He showed that the latter is superior in retaining strength. He also showed that synthetic elastomers lose up to 73% of initial force during the first day, but force decay continued at a slower rate during the rest of the 21 day period. He also indicated that changing test conditions will have an effect on the modulus of elasticity.

Die-cut verses injection moulded:

A randomized clinical trial by Bousquet et al. (2006), comparing force decay of die-cut stamped and injection moulded elastomers, concluded that both types behave in a similar way. By contrast Hershey and Reynolds (1975) had showed that die cut stamped performed better in terms of force decay compared to injection moulded type.

The effect of pre-stretching:

Kim et al. (2005) questioned the benefit of pre-stretching power chain as he showed that during the first hour, pre-stretching of elastomeric modules yielded significantly lower initial force than the control. But both behave similarly from 1 to 4 weeks. Similar results where obtained by Lam et al. (2002). In clinical practice elastomeric chain is usually extended to 50-100% of its initial length with or without pre-stretching (Rock et al., 1985). The amount of pre-stretching and the test elongation used in the International Standards Organisation (ISO) protocol is 300% and 200% respectively, with an additional extension to 300% before residual force testing. This is much greater than described in the reviewed literature and is likely to significantly influence the data obtained, making comparison extremely difficult and conclusions of limited value. The reason for pre-stretching the sample a second time before residual testing is unknown, it is not analogous to methods in clinical use and its methodological value should be questioned.

Review of the current literature suggests the following:

1- Different coloured elastomeric chains have different decay force especially the first 24 h.

2- In some brands, different colours exhibit similar mechanical properties, but other brands showed colour specific effect.

3- Synthetic elastomeric chains lose approximately 20-70% of their initial force in the first 24 h and 40-85% after 21 to 28 days.

4- Elastomeric chain undergoes more force decay in fluid than in dry environments.

5- Closed chain has a higher initial force.

6- Die-stamped and injection-moulded elastomeric chains behave similarly, although there is some evidence of slightly superior behaviour in the former.

7- Pre-stretching is of doubtful benefit over a clinically useful period of three to six weeks.

8- Changes in temperature have a significant effect. The higher the temperature the greater the force loss. Thermal cycling, in contrast, may improve the load- relaxation behaviour.

9- All chains produced forces compatible with physiologically sound tooth movement.

The aims of the current study are:

1. To investigate whether different coloured orthodontic elastomeric chains have different force decay.
2. To compare force decay of 3 different brands.

The null hypotheses tested were:

1. All coloured elastomeric chains have the same decay force.
2. All brands have similar force decay.

6. MATERIALS AND METHODS

The International Organization for Standardization (ISO) has recently developed guidelines which specify the method by which the physical properties of orthodontic elastomeric materials should be tested (ISO/TC 106, 2005, Draft). The ISO is a worldwide federation responsible for preparing international standards for industry and commercial use. The recent guidelines for orthodontic elastomeric auxiliaries differ significantly from any methodology described in the literature.

Three different coloured elastomeric chains from three different suppliers were chosen. Details of these materials are given in Table 1.

Table 1. Specimen characteristics

	Manufacturer	Morphology	Colour	Specimen	Test length
3M	3M, Monrovia	Medium spaced	clear, blue, grey	5 links	16.1 mm
TP	TP Orhtodontics, Inc,100 Center Plaza.La Porte,IN 46350 USA	Medium spaced	clear, blue, grey	5 links	18 mm
GAC (DENTSPLY)	MediMark Europe, Cedex, France	Medium spaced	clear, blue, grey	5 links	17.15 mm

Testing was carried out by a single operator (HA), using an Instron Universal Testing Machine (Model No. 1195, Instron Limited, High Wycombe, Bucks., UK) with 50 N tension load cell (type: 2511/111). The testing jig fixed to the load cell consisted of two aluminium plates with two 0.9 mm diameter stainless-steel rods set into the base. Testing was carried out at room temperature (23 ± 2^{o}C) according to ISO/DIS 21606. Three custom acrylic jigs with two acrylic rods, linked with adjustable stainless steel bolts. 1.0 mm diameter stainless-steel dowels. This 'female' portion engages with the 0.9 mm diameter 'male' dowels on the test jig allowing the specimen to be moved to and from the acrylic storage jig, with no change in elongation and loading (Figures 1 & 2).

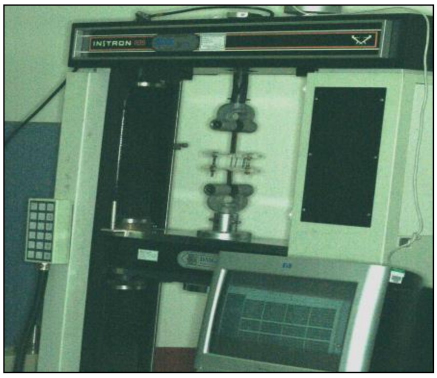

Fig 1 Transfer of specimen onto test plates mounted in Instron Universal Testing Machine using custom storage jig

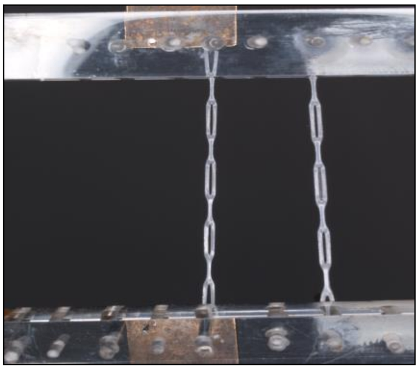

Fig 2 shows the custom storage jig engaging into the dowel.

Prior to use the specimens were kept at room temperature (23 ± 2^{o}C). All specimens were uncoiled from the reel and cut into five module units using a blade. Ten samples from each group were measured from the inner surface of the lumen of the terminal modules. The mean of these was used as the test length. Samples were placed into a sealed glass container with distilled water and placed into an incubator maintained at 37^{o}C.

Initial force testing:

1. The jig was adjusted to the specimen test length and the specimen extended to four times the test length at a cross head speed of 100 mm /min.

2. Hold for five seconds.

3. Relax the extension at 100 mm/min to an extension of three times the test length.

4. Hold for 30 seconds.

5. Measure the force in Newtons (N).

6. Repeat 10 times for each sample type (Colours & manufacturers, n= 90).

Following initial force testing, each specimen was transferred, at constant extension, from the testing jig to the custom acrylic storage jig set at three times the test length. The specimens were then stored in distilled water at 37^{o}C. The specimens, at constant extension, were then returned to the testing jig for residual force testing.

Residual force testing:

1. Starting at three times the test length, extend to four times the test length at a cross head speed of 100 mm/min.
2. Hold for five seconds.
3. Relax to three times the test length at 100 mm/min.
4. Hold for 30 seconds.
5. Measure force in Newton.
6. Repeat for all samples.

7. RESULTS

Data was analyzed using Stata 10.0. Significance was pre-determined at α = 0.05. The experimental design was a balanced repeated measures ANOVA. Since all terms were significant in the full model, each material was analyzed separately to evaluate the effect of time and colour on force decay. Contrasts were used to evaluate these effects using Sidak's correction for multiple comparisons. Means and standard deviations are shown in Appendix 1. All variables (time, material, and colour) where statistically significant as shown in Table 2.

Table 2. Analysis Of Variance (ANOVA)-balanced repeated measures, full model

Source	df	F	Prob > F
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Time	4	14438.37	0.0001
time*material	8	426.59	0.0001
time*colour	8	60.46	0.0001
time*material*colour	16	69.00	0.0001

Comparing paired colours in each material, Table 3 indicates that all colours show statistically significant differences, except for the 3M clear and grey and GAC blue and grey.

Table 3. Significance of Paired colours comparisons within each brand

3M

Comparison	Overall
Clear-Blue	0.001
Clear-Grey	0.725
Blue-Grey	0.001

TP

Comparison	Overall
Clear-Blue	0.001
Clear-Grey	0.001
Blue-Grey	0.001

GAC

Comparison	Overall
Clear-Blue	0.001
Clear-Grey	0.001
Blue-Grey	0.812

Table 4. Significance of colour and time within each brand

Brand	Time Period	Clear	Blue	Grey
3M	1-2 (0-1 h)	0.001	0.001	0.001
	2-3 (1h-24 h)	0.001	0.001	0.001
	3-4 (24 h-7 days)	0.001	0.001	0.001
	4-5 (7 days-28 days)	0.031	0.001	0.871
TP	1-2 (0-1 h)	0.008	0.001	0.001
	2-3 (1h-24 h)	0.999	0.001	0.008
	3-4 (24 h-7 days)	0.001	0.001	0.001
	4-5 (7 days-28 days)	0.889	0.228	0.001
GAC	1-2 (0-1 h)	0.001	0.001	0.001
	2-3 (1h-24 h)	0.001	0.001	0.001
	3-4 (24 h-7 days)	0.001	0.002	0.001
	4-5 (7 days-28 days)	0.001	0.001	0.001

When considering the significance of time intervals and its effect on each colour, Table 4 shows that 3M time intervals are all significant for all colours except the grey in the 7 days-28 days period. For TP clear, the statistically significant periods are 0-1 h and 24 h-7 days. For the TP blue all time intervals where significant except in 7 days-28 days period, whereas TP grey all time periods where significant. However, time was statistically significance for GAC in all the intervals for all the colours.

Figure 3 shows the force decay in 3 colours chains; in all brands, blue colour lost most of its residual force compared to the rest of the colours. TP grey and clear maintained their residual force above 1.0 N at 28 days. GAC has the least residual force.

3M and GAC had initial force ranging from 1.9-1.4 N where as TP grey has initial force at 2.3 N. After 1 h, residual force dropped further to 0.85 N for GAC blue but TP grey maintained residual force above 2.0 N. At 24 h TP grey maintained the residual force above 2.0 N but 3M and GAC dropped below 1.5 N.

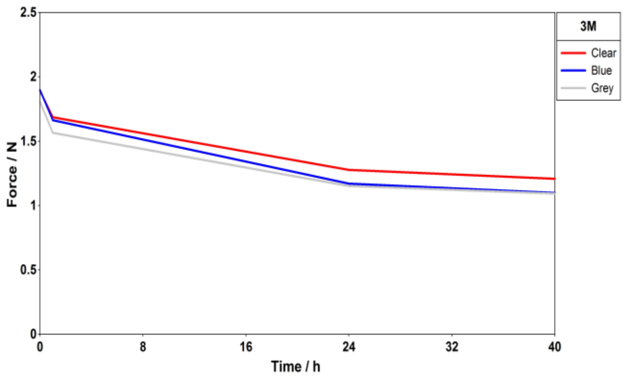

Fig. 3A

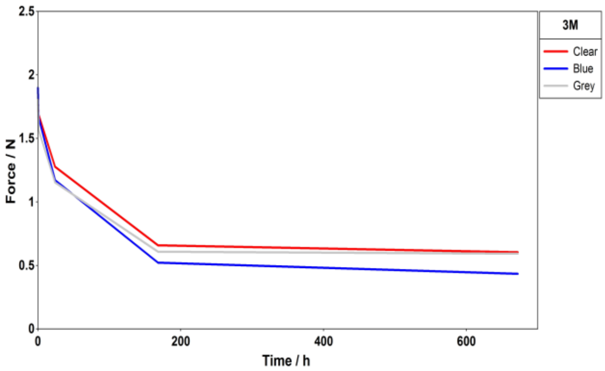

Fig. 3B

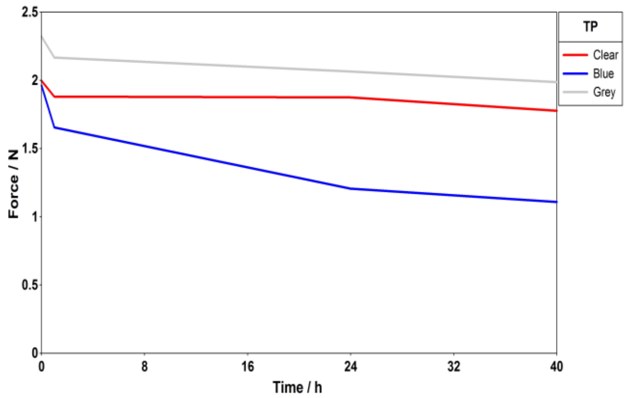

Fig. 3C

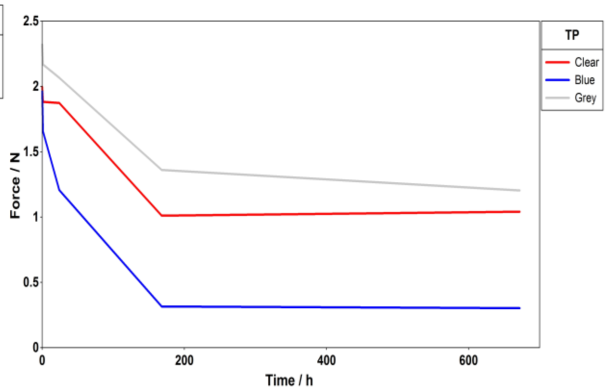

Fig. 3D

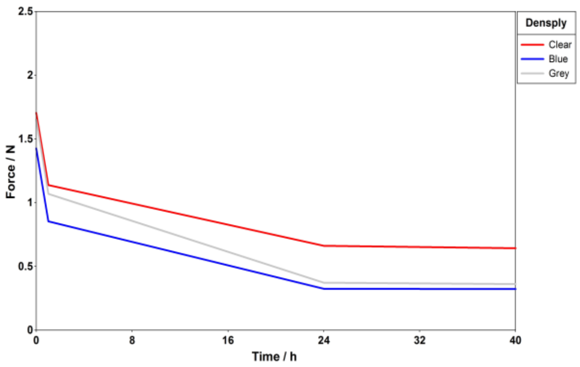

Fig. 3E

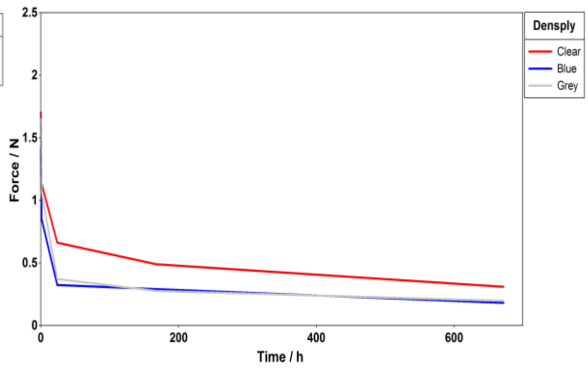

Fig. 3F

Fig 3. Force decay in 3 coloured chains (clear, red line; blue, blue line; grey, grey line) for three manufacturers 3M (A&B), TP (C&D) and GAC (E&F).From T_0 to 40 h (A, C, E), 2nd from T_0 to 28 days (B, D, F).

7. DISCUSSION

The aim of this study was to investigate whether different coloured orthodontic elastomeric chains have different force decay, using the ISO standards 2005, for testing orthodontic elastomeric modules (draft). As mentioned earlier, there are different methods of testing these materials. The main advantages of the latest ISO standards are; first it set up standardized method of testing, so further comparisons can be made. Second, the force and elongation formula used can be applied to any elastomeric modules.

Overall findings:

The initial force levels range from 2.3 N (TP grey) to 1.5 N (GAC blue), this indicates variable forces delivered by different brands, and this is similar to the range of forces in previous studies (Appendix 2). Early force decay during the first 24 h was greatest in GAC chains; GAC had residual force of 0.6-0.33 N, where as all other chains retain force greater than 1.6 N in this early time period.

At 7 days residual force levels range from 0.6 N to 0.27 N, except for TP grey and clear as they maintained residual force levels range from 1 N to 1.4 N. This clearly indicates that E-chains are superior to the rest of the samples. All samples showed minimal force decay changes in the 7-28 day period. In the long term test (28 days) TP grey and clear retain considerably higher residual forces than the other chains.

Effect of colours:

In this study (Table 3) showed the significance of paired colours comparisons within each brand, and it clearly indicate that when comparing different colours within each brand, that the majorities are statistically significant, except 3M clear and grey and GAC blue and grey.

The blue colour had the highest force decay among tested brands (Table 5). Clear, was superior in both 3M, and GAC, but grey was superior in TP compared to the other colours. The findings in this study agree with previous studies (Baty et al., 1994; Lam et al., 2002; Renick et al., 2004; Williams and von Fraunhofer, 1989), that different colours behave differently in term of force decay.

Very few studies available in the literature tested different coloured elastomeric chains. Most studies on elastomeric modules or chains have come to the conclusion that different coloured elastomeric modules require different distraction forces (Baty et al., 1994; Lam et al., 2002; Renick et al., 2004).

Some studies have attributed the differences in behaviours of different colours of elastomeric chains and modules to the fact that certain types of fillers have been incorporated into the polymer to provide colour. Whether the filler can form cross-links with the polymer, this may have an effect on the properties, and this may be inflected in the mechanical properties of the material, but there where no conclusive evidence (Baty et al., 1994; Lam et al., 2002).

Dowling et al. (1998), conducted a study on coloured modules, and showed that there are stastically significant differences ($p<0.001$) exist with regard to friction between the five types of elastomeric modules. The clear round modules exhibited the lowest frictional value. And when modules immersed in a simulated oral environment, this affected different modules in different ways with regard to friction, for some, the frictional forces increased, while for others the force decreased or maintained constant. The drawback of this study was the use of one brand ('A'-company, Amersfort 3800, The Netherlands). Also (Lam et al., 2002) compared preloading and after use coloured ligatures and concluded that different colours ligatures have different tensile strength, and that some significant differences also exist between different brands.

E-chains versus others;

As mentioned earlier, (Table 2) shows that all brands are statistically significantly different. Figure 3 clearly describes the behaviour of each material over time. TP grey and clear (E-chain) had the highest initial force values and continued to be superior to the others by maintaining 50% of their original force up to 28 days. TP blue was not behaving like E-chain; in fact it falls under the force range of 3M.

Looking at Figure 3 all the 3M colours behave similarly during the tested periods (gradual force loss), although by referring to (Table 3) they are statistically significantly different, except clear and grey. In general, 3M have less force compared to TP E-chain, but the advantage of 3M is that, gradual force loss took place during the tested period.

GAC was the worst in term of force loss over time. Table 4 shows that all time periods for all the colours where significant, and as it is shown in Figure 3) not only that the initial force is the lowest compared to the 3M and TP, but also the force decay is the highest.

This study agrees with previous investigators as they shown that different brands have different force decay (De Genova et al., 1985; Killiany and Duplessis, 1985; Renick et al., 2004).

Percentage of force decay (%);

Table 5. Percentage (%) and mean residual force in Newton (N)

Clear	0	1 hr	24 hrs	7 days	28 days
3M	100% (1.9 N)	88.80% (1.7 N)	66.60% (1.3 N)	35.11% (0.66 N)	32.40% (0.6 N)
TP	100% (1.99 N)	92.60% (1.88 N)	92.10% (1.87 N)	50.20% (1.01 N)	51.20% (1.04 N)
GAC	100% (1.7 N)	67% (1.14 N)	36.50% (0.62 N)	28.80% (0.49 N)	18.20% (0.31 N)
Blue					
3M	100% (1.89 N)	88.30% (1.7 N)	56.10% (1.2 N)	27.50% (0.52 N)	27.50% (0.44 N)
TP	100% (1.96 N)	84.20% (1.66 N)	61.20% (1.21 N)	16.30% (0.32 N)	15.40% (0.30 N)
GAC	100% (1.43 N)	59.40% (0.85 N)	22.40% (0.33 N)	20.30% (0.29 N)	12.60% (0.18 N)
Grey					
3M	100% (1.81 N)	86.20% (1.6 N)	73.70% (1.2 N)	33.70% (0.61 N)	32.60% (0.59 N)
TP	100% (2.3 N)	93.50% (2.2 N)	89.20% (2.1 N)	58.62% (1.4 N)	51.70% (1.2 N)
GAC	100% (1.7 N)	64.80% (1.1 N)	22.40% (0.37 N)	16.70% (0.27 N)	12.70% (0.19 N)

Looking at Table 5 at end of 28 days, % of residual force can be sub-categorised into 3 main groups as follow;

Group 1: (> 50% residual forces); under this group TP E-chain grey and clear; they have maintained 50% of there initial force until the end of 28 days.

Group 2: (30%- 20%) residual forces; under this group 3M clear, grey, and blue.

Group 3: (< 20%) residual forces; under this group TP blue, and all colours for GAC.

In this study, all have shown to loose some force in the first hour (Table 5), ranging from 40% loss in decay rate (GAC, blue), to just 6.5% (TP grey). At 24 h GAC had lost 78% of its original force, but TP clear lost only 8% of its original force. At 7 days, TP grey and clear lost about 50% of their original force, but they continued to retained it up to the end of the 28 days, where as 3M, TP blue, and GAC had lost about 75% of their original force at the end of 28 days.

The residual forces at the end of 24 h (Table 5), 3M and TP, they have retained 92-56% of their original forces. This result is similar with previous work on decay rate of elastomeric chains (Bousquet et al., 2006; Lu et al., 1993). It can be seen clearly from (Table 5), that GAC blue had lost 40% of its original force in 1 h, and continued to loose most of its force (88%) at the end of 28 days, where as TP clear and grey (E-chains), retain more than 90% of their original forces at the end of 1 hour, and where able to retain 50% of their original force at the end of 28 days.

It must be mentioned here that it is not accurate to compare the force decay of different materials in percentage only, but we have to take into account the actual force available at any given time.

8. CONCLUSIONS

Under the conditions in this experiment the following conclusions where reached:

1- E-chains (TP grey and clear) are superior to the rest of the chains.

2- TP blue had the highest decay force compared to TP grey and clear.

3- GAC had the least initial force and the highest decay force.

4- Blue generally had the highest decay force.

5- Most force decay was within 1-7 days, except GAC which had the most force decay in the first 24 h.

6- The first null hypothesis is rejected as different colours had variable force decay.

7- All brands gave different force decay, so the second null hypothesis is also rejected.

Clinical relevance;

Under the conditions of this experiment, blue colour chains had the highest force decay. TP E-chain (grey and clear) had the highest initial force of (2 N) and retained more than 50% of their original force (1 N) at the end of 28 days. GAC and (3M & TP blue) retained less than 1 N of force after 24 h and 7 days respectively. 3M maintained gradual force decay during the tested period. This longer term variability may be of clinical importance if the residual force drops below the threshold of force delivery required for orthodontic tooth movement.

With all the advances in polymers, it seems that not all the brands available can meet the minimum required forces for space closure. It is impossible to apply constant force using any of the available means to close space, as all experience some force decay. There are several options to close spaces, one is by using nickel-titanium closed coil spring, which can retains most of it is initial force (Nattrass et al., 1998), but it will be difficult to use in the anterior region. In the other hand, power chains are extensively used in space closure as they are easy to place, accepted well by the patients, cheaper compared to coil spring, and some, like E-chains or E-links, can actually deliver the amount of force reasonably as good as coil spring, as the work by (Nightingale and Jones, 2003), demonstrated that both closed coil spring and E-chain close spaces at a similar rate. While others (Nattrass et al., 1998; Samuels et al., 1993; Sonis, 1994), have found nickel titanium coil springs to be more effective clinically.

9. EVALUATION OF METHODS AND FURTHER WORK

This study implemented the ISO standard for testing orthodontic elastomeric auxiliaries. While this protocol is simple and in principle should be applauded, it falls short in a number of areas of providing useful and clinically relevant information.

The ISO testing protocol does not extend beyond 24 h and whilst it is accepted that the majority of force decay occurs within the initial 24 h the evidence would suggest that force reduction does continue at a slower and variable rate (Andreasen and Bishara, 1970; De Genova et al., 1985; Nattrass et al., 1998).

The tension load cell of the instron testing machine used in this experiment has a force of 50 N range; it will be more accurate to use a more sensitive cell. As more advances in the field of polymers, more tests are needed to compare different colours from different suppliers.

It will be an advantage to record the permanent elongation and to compare the results with previous studies. A randomised clinical trial to compare the initial and after use will be more accurate to measure the force decay.

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APPENDICES

1. Mean (M) and standard deviation (SD) for each brand, 10 samples of each colour tested in time intervals; initial, 1 h, 24 h, 1 week (168 h), and 4 weeks (672 h).

			Hours			
		0	1	24	168	672
Brands	Clear	10	10	10	10	10
3M	M	1.891	1.686	1.277	0.658	0.605
	SD	0.38	0.07	0.031	0.021	0.013
	Blue	10	10	10	10	10
	M	1.898	1.663	1.171	0.522	0.435
	SD	0.048	0.052	0.054	0.019	0.023
	Grey	10	10	10	10	10
	M	1.805	1.566	1.153	0.608	0.593
	SD	0.026	0.044	0.72	0.014	0.007
TP	**Clear**	10	10	10	10	10

	M	1.997	1.882	1.874	1.012	1.04
	SD	0.125	0.077	0.068	0.063	0.052
	Blue	10	10	10	10	10
	M	1.962	1.656	1.207	0.316	0.302
	SD	0.017	0.028	0.009	0.012	0.004
	Grey	10	10	10	10	10
	M	2.321	2.167	2.065	1.36	1.203
	SD	0.095	0.121a	0.084	0.037	0.007
GAC	**Clear**	10	10	10	10	10
	M	1.704	1.137	0.622	0.489	0.309
	SD	0.018	0.024	0.02	0.01	0.01
	Blue	10	10	10	10	10
	M	1.426	0.853	0.325	0.29	0.182
	SD					
	Grey	10	10	10	10	10
	M	1.653	1.069	0.372	0.277	0.197
	SD	0.036	0.04	0.041	0.016	0

2. Comparison of force decay in elastomeric chains in previous studies

Study	design	(grams)	decay after 1 hour	decay after 24 hours
Hershey and	in vitro	284-573	36%	53%
Reynolds,1975				
Wong, 1976	in vitro	300-450	No information	No information
Ash and	in vitro and	603-694	37-48 %	48-58 %
Nikolai, 1978	in vivo		45-48 %	58-61 %
Young and	in vitro	180	31-43 %	43-56 %
Sandrik, 1979				
De Genova et al, 1985	in vitro	241-436	No information	No information
Kiliany and	in vitro	330-375	No information	23-55 %
Duplessis, 1985				
Kuster et al, 1986	in vitro and	286-352	No information	18-23 %
	in vivo	279-315		31-41 %
Lu et al, 1993	in vitro	364-370	20-55 %	20-255 %
Stevenson and	in vitro	485-525	No information	32-68 %
Kusy, 1994				
Talounis et al., 1997	in vitro	279-352	53-68 %	53-68 %
Bousquet et al, 2006	in vivo	200	15-20 %	17-21 %
This study	in vitro	232-174	6.5-40 %	8-78 %