Journal of Orthodontics, Vol. 29, 2002, 37–43

SCIENTIFIC SECTION

Strength decay of orthodontic elastomeric ligatures

T. V. Lam, T. J. Freer, P. J. Brockhurst and H. M. Podlich
University of Queensland, Australia

Abstract

Aim To evaluate, over a 12-week period, the tensile strength (TS) and extension to TS of elastomeric ligatures (both clear and coloured) obtained from two companies.

Setting *Ex vivo* study.

Method Seven replicates of five ligatures from two orthodontic companies were tested using an *ex vivo* assembly which simulated a clinical situation.

Results The ligatures tested had a similar TS decay pattern, with the TS gradually decreasing over the duration of the study. The Unitek ligatures exhibited a greater TS than their respective Ormco ligatures. Generally, all of the ligatures tested experienced an increase in the extension to TS over time. The pre-stretching procedure used in this study did not produce any long-term detrimental effects on the TS and extension to TS of the ligatures tested.

Conclusions The results of this study confirm there are differences in TS, and extension to TS between clear and coloured elastomeric ligatures, and that some significant differences also exist between different brands of elastomeric ligatures.

Index words:
Elastomerics, ligatures, pre-stretching, tensile strength.

Received 15 December 2000; accepted 28 June 2001

Introduction

There are few reported studies that measure the strength characteristics of orthodontic elastomeric materials. In one study, Wong examined the tear strength of Ormco Power Chain (Ormco, Glendora, USA) and Unitek**[Q1]** Alastik chain over a 3-week period.[1] He found that the Unitek Alastik chain fractured at a slightly higher force than the Ormco Power Chain at all times after being submerged in a 98°F water bath for up to 21 days. However, the Ormco chain fractured at a greater stretch, almost 100 per cent greater than the Unitek chain. He also reported that the fracture tests of both materials showed a great variability in the range of tensile strength (TS).

TS can be defined as the *maximal* stress a structure can withstand before fracture/rupture.[2] This was obtained from force-extension curves produced as each elastomeric ligature was stretched until it fractured. This is represented by the peak force level prior to the ligature breaking.

In a later study Young and Sandrik examined tensile failure for CK and C2 Alastik chains, however, they found that the breaking strength for both groups was similar.[3] More recently, the TS of two types of elastomeric separators, regular and barium-filled, was measured after specified intervals of cold sterilization. They concluded that cold sterilization might cause a small degree of degradation in the TS of barium-filled separators not found in regular separators. The clinical significance of this small change was unknown.[4]

Another property of elastomeric ligatures that is of interest to orthodontists is the extension to TS. Extension to TS is measured as the extension at which the peak force level (or TS) occurred. This property provides an indirect measure of the 'toughness' of these ligatures.[2] This has been described as the property of being difficult to break, and it can be defined as the energy required to fracture a material.[2] Ligatures that have a high extension to TS (that is, they have to be stretched a long distance before reaching their TS) are more difficult to break whereas those that having low extension to TS are more easily broken.

There are no known studies that have evaluated the extension to TS of elastomeric ligatures and only one study has been reported that measured the TS of new and

Address for correspondence: Professor T. J. Freer, School of Dentistry, University of Queensland, Turbot Street, Brisbane, Queensland 4000, Australia.
E-mail: t.freer@mailbox.uq.edu.au

used ligatures.[5] This was an *in vitro* study that investigated the behavioural characteristics of elastomeric ligatures with regard to their effect on frictional resistance and their TS (the authors referred to the TS as the 'failure load force'). Five types of elastomeric ligatures were tested. These included four ligatures produced by injection moulding and one produced by die punching. They concluded that a wide range of failure load forces was observed between the five types of ligatures and immersion in a simulated oral environment resulted in a reduction of up to 35 per cent in TS for all types of ligatures.

A relatively recent innovation is the colouring of elastomeric ligatures. Dowling *et al.*[5] reported that the clear ligatures in their study demonstrated the lowest TS when compared with the grey and orange ligatures. However, they only examined ligatures produced by one company. It would be useful to determine whether similar results would be obtained when evaluating different ligatures from a variety of companies. This was recently investigated and it was found that the addition of colouring materials to ligatures manufactured by Ormco altered their force behaviour. However, those produced by Unitek were not affected. The effects on both the TS and extension to TS after pre-stretching different types of elastomeric ligatures are still unknown.[6]

This study aimed to evaluate any changes in the TS and the extension to TS in clear and coloured elastomeric ligatures from two manufacturers over a 3-month period in a simulated oral environment. The effects of pre-stretching on these characteristics were also examined.

Materials and methods

Injection-moulded elastomeric ligatures (clear, blue, green, grey, and purple), obtained from Ormco and Unitek were examined. Seven duplicates of each colour of ligature from both companies were tested at zero, 24 hours, and 1, 2, 4, 8, and 12 weeks. Seven duplicates of clear ligatures from both companies were pre-stretched and also tested at the same time intervals (Table 1).

A bracket-jig was fabricated by brazing an Ormco Mini-Diamond bracket (0.018-inch slot) to one end of a metal jig. The test-jig was composed of two half-sections with a total cross-sectional dimension equivalent to that of the bracket-jig and storage-jigs.

A 60-degree V-shaped (convex) key was cut into the free end of both the bracket-jig and test-jig. The storage-jigs had 60-degree V-shaped (concave) keys cut into both of their ends. Every ligature tested in this study was initially engaged over the bracket on the bracket-jig to simulate the clinical application of a ligature onto a bracket (Figure 1). The bracket-jig was then linked up to the appropriate storage-jig for the subsequent transfer of the ligature from the bracket-jig over to its storage-jig. The storage-jigs simulated the inner section of the bracket and allowed seven ligatures to be placed along them as though they were engaged on the bracket.

A total of 84 storage-jigs were used, one for each of the 12 test groups at each time interval. The storage-jigs were placed in separate plastic bottles containing artificial saliva, which was replaced weekly, and these bottles were stored in an oven maintained at 37 ± 1°C and removed at each time interval tested.

Table 1 Elastomeric ligatures used

Manufacturer	Brand name	Size (inch) provided by manufacturer	Colour	Re-order number abbreviation*	Test group
Ormco	.120 Power 'O' modules	0.120 (outer diameter)	Clear	640–0075	Orm prestr. Orm clear
			Blue	640–0102	Orm blue
			Green	640–0106	Orm green
			Grey	640–0078	Orm grey
			Purple	640–0100	Orm purple
Unitek	Quik-Stik A-1 Alastik modules	0.123 (outer diameter)	Clear	406–417	Uni prestr. Uni clear
			Blue metallic	406–734	Uni blue
			Lime	406–708	Uni green
			Grey	406–407	Uni grey
			Purple metallic	406–733	Uni purple

*Clear ligatures were tested in both the pre-stretched and unstretched states, whereas all coloured ligatures were tested in the unstretched state only.

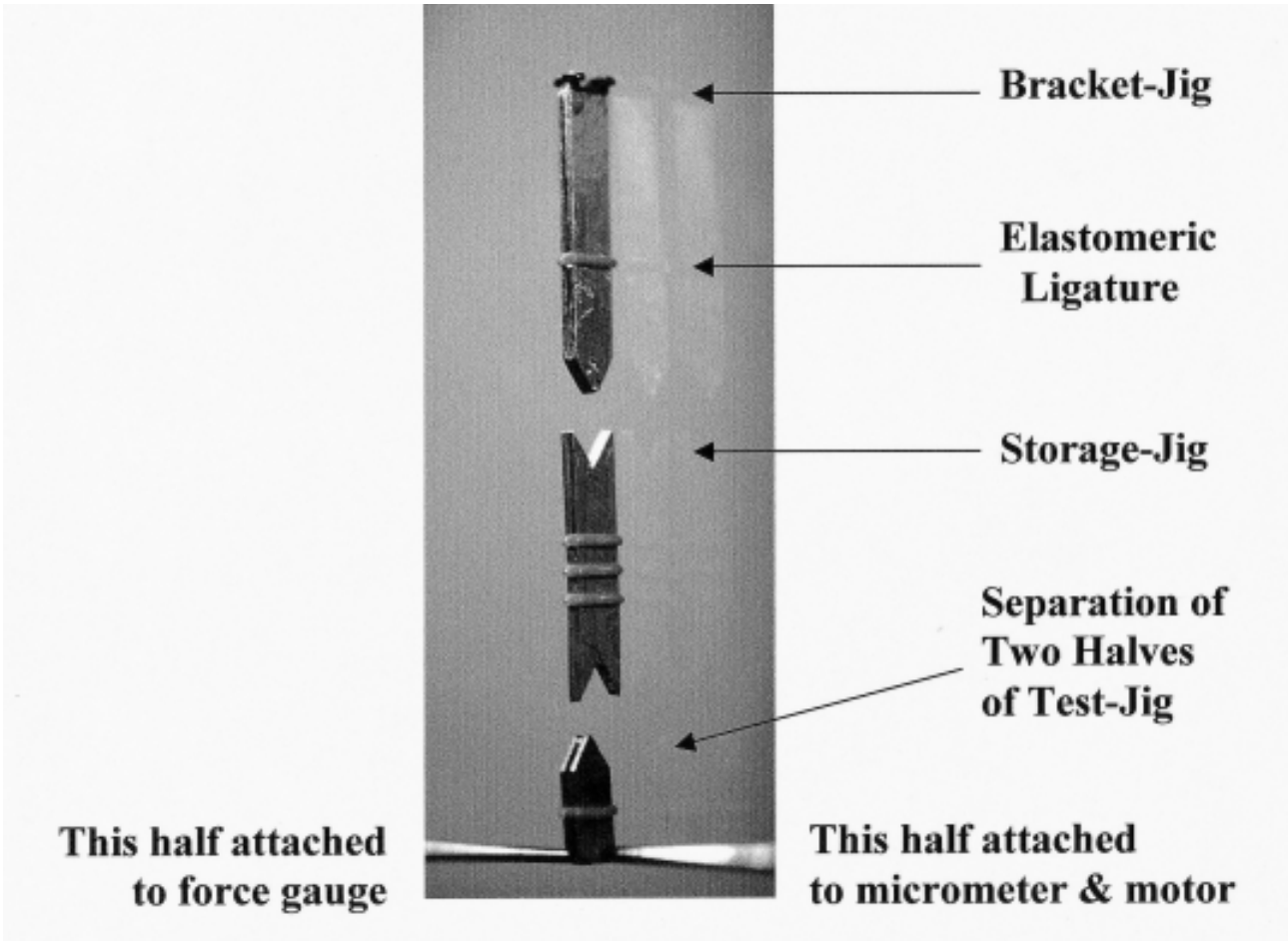

Fig 1 The bracket and storage jig.

The ligature pre-stretching procedure involved securing two straight sections of stainless steel wire (0.8-mm diameter) 6 mm apart onto a rectangular block of wood. The ligatures were then slipped over one of the wires and gradually pre-stretched 6 mm (approximately twice their length), using the second wire as a guide. The ligatures were then allowed to relax briefly before being pre-stretched a further two times. Pre-stretching was performed immediately prior to engaging these ligatures over the bracket on the bracket-jig.

The testing assembly had one half of the test-jig attached to an electronic force gauge (Mecmesin Advanced Force Gauge AFG-25N; Mecmesin Ltd, Broadbridge Heath, West Sussex, UK), while the other half was fixed to a micrometer with a digital output (Mitutoyo 164 Series Digimatic Head; Mitutoyo Corporation, Minato-ku, Tokyo, Japan). A motor and circuit board timer were also connected to the latter end of the assembly to allow the second half of the test-jig to be moved either towards or away from the first half.

Prior to each test, the two halves of the test-jig were brought together and the elastomeric ligature to be tested was transferred from its storage-jig to the test-jig. The motor and circuit board timer separated the two halves of the test-jig, stretching the ligature at a constant rate of 25 mm/min until it broke. The rate of extension of each ligature was kept constant. As each ligature was stretched, both the force (N) and extension (mm) were measured simultaneously. An IBM-compatible computer recorded this data and the information was subsequently plotted using Microsoft Excel 97 (Microsoft Corporation, Redmond, USA) in order to produce a force-extension curve. The TS was obtained from this curve and was represented by the peak force level. The extension to TS was also recorded.

Statistical analysis

An analysis of variance (ANOVA) was carried out on both the TS and extension to TS readings. Means of the

12 test groups were then compared using the least significant difference (lsd) at the 5% statistical significance level.

Results

Tensile strength component

The mean TS at each time interval for all 12 ligatures tested are presented in Table 2. Initially, the mean TS ranged from 19.2 to 20.6 N for the Ormco ligatures and from 20.4 to 21.8 N for the Unitek ligatures. The ligatures tested in this study experienced an overall decrease in the TS over time, despite some slight increases for several ligature groups occurring during the test period. By 12 weeks, the mean TS had reduced to 78–85 per cent of the initial TS (16.7–18.0 N) for the Unitek ligatures, and 73–91 per cent (14.2–17.4 N) of the initial TS for the Ormco groups.

The ANOVA table for the TS readings is shown in Table 3, with 'Treatments' denoting the 12 different test groups and 'Reps' denoting the seven duplicates of each group. There was a strong treatments by time interaction (Treatments*Time) so comparisons of means within each time interval were necessary. At each time interval, a pair of means given in Table 2 are significantly different at the 5% statistical level if their difference exceeds the lsd quoted. Most Unitek ligatures had a higher mean TS than the respective Ormco ligatures at each time interval. The Unitek green and grey ligatures had a mean TS between 13–29 per cent (2–5 N) greater than the respective Ormco ligatures over the entire test period. There was a slight increase in the initial mean TS for pre-stretched clear ligatures compared with unstretched ligatures from both companies.

The clear (pre-stretched and unstretched) ligatures tended to exhibit a higher mean TS than the coloured ligatures of the same company throughout the study. The Ormco grey and green ligatures had a significantly lower TS than the blue and purple ligatures from 24 hours onwards. The only notable difference observed between the Unitek coloured ligatures over the study period, was at 2 and 4 weeks when the blue ligatures had a significantly smaller TS.

Table 2 Mean tensile strength (N) over time for all test groups

	0 Hour Mean (SD)	24 Hours Mean (SD)	1 Week Mean (SD)	2 Weeks Mean (SD)	4 Weeks Mean (SD)	8 Weeks Mean (SD)	12 Weeks Mean (SD)
Orm prestr.	20.65 (0.96)	18.98 (0.87)	19.23 (0.71)	18.73 (0.71)	18.18 (0.88)	17.57 (0.64)	17.26 (1.12)
Orm clear	19.21 (1.39)	18.60 (1.14)	18.55 (0.47)	18.12 (1.06)	17.89 (0.69)	17.39 (0.60)	17.44 (0.82)
Orm blue	20.24 (1.14)	18.31 (0.57)	18.30 (0.62)	17.96 (0.70)	17.46 (0.84)	16.79 (0.48)	15.73 (0.58)
Orm green	19.41 (0.97)	16.24 (0.79)	16.44 (0.95)	15.97 (0.51)	15.11 (0.28)	15.05 (0.64)	14.89 (0.74)
Orm grey	19.49(1.02)	16.70 (0.85)	16.87 (0.75)	16.24 (0.44)	15.62 (0.66)	14.56 (0.86)	14.16 (0.69)
Orm purple	20.19 (1.34)	17.75 (1.08)	18.16 (0.81)	17.74 (0.58)	17.19 (0.58)	16.77 (0.69)	16.20 (0.62)
Uni prestr.	21.82 (0.62)	20.97 (1.44)	20.47 (1.06)	20.71 (1.19)	19.68 (1.19)	18.22 (1.26)	17.96 (1.58)
Uni clear	21.69 (0.88)	20.91 (0.97)	20.42 (1.56)	20.19 (1.01)	19.24 (1.28)	18.16 (0.95)	17.52 (0.84)
Uni blue	20.44 (0.93)	20.19 (1.51)	20.00 (0.92)	18.48 (0.91)	16.83 (0.98)	17.09 (0.87)	16.70 (0.81)
Uni green	21.51 (1.23)	20.98 (1.81)	20.97 (2.50)	19.82 (1.95)	17.76 (1.39)	16.97 (0.67)	16.84 (0.92)
Uni grey	21.62 (0.92)	21.19 (1.26)	21.04 (1.33)	20.70 (0.99)	19.40 (1.82)	18.01 (0.79)	17.86 (1.03)
Uni purple	20.69 (0.96)	20.89 (1.77)	20.63 (1.61)	20.46 (1.99)	19.02 (1.05)	17.78 (0.87)	17.54 (0.69)

Least significant difference = 0.86 (at 5% statistical level).

Table 3 Statistical analysis of tensile strength readings using ANOVA

Source	DF	Sum of squares	Mean squares	*F*-value	*P*-value
Treatments	11	952.014	86.547	22.299	<0.0001
Reps (treatments)	72	279.450	3.881		
Subtotal	83	1231.465			
Time	6	977.0336	162.839	240.87	<0.0001
Treatments*Time	66	142.725	2.163	3.20	<0.0001
Time*Reps (treatments)	432	292.057	0.676		
Total	587	2643.281			

Extension to tensile strength component

The mean extension to TS for all 12 ligatures tested is presented in Table 4. Initially, the mean extension to TS ranged from 8.3–10.0 mm for the Unitek ligatures and from 6.9–10.4 mm for the Ormco ligatures. All of the ligatures tested in this study experienced an overall increase in the extension to TS over time. There were, however, some slight decreases in the extension to TS for several ligature groups occurring during the 24-hour to 1-week period (the same period when the TS increased). At 12 weeks, the mean extension to TS had increased to a range of 9.4–11.5 mm (12–25 per cent increase over the initial extension) for the Unitek ligatures, and 9.3–13.6 mm (27–38 per cent increase over the initial extension) for the Ormco groups.

The ANOVA table for the extension to TS is presented in Table 5. The strong treatments by time interaction again meant that comparisons of means within each time interval were necessary. The lsd in Table 4 denotes the smallest amount by which two means must differ to be significantly different at the 5 % statistical level. This revealed that the pre-stretched ligatures demonstrated a slight increase in the mean extension to TS compared with their unstretched equivalent. The initial increase in extension to TS for the Unitek brand was 0.3 mm (or 3 per cent) and 0.7 mm (or 10 per cent) for the Ormco ligatures. Only the Ormco brand demonstrated a statistically significant difference.

The Ormco clear (pre-stretched and unstretched) ligatures exhibited a lower extension to TS than the Ormco coloured ligatures at all time intervals. This difference was 2.3–3.4 mm (or 24–28 per cent) lower than for the coloured ligatures. There were no significant differences between the Unitek pre-stretched and unstretched clear ligatures in extension to TS. Ormco ligatures exhibited greater extension to TS than comparable Unitek ligatures.

Discussion

The initial mean TS exhibited by the ligatures in this study ranged from 19.2–21.8 N. These figures are slightly higher than those previously reported of 15.2–19.8 N for the injection-moulded ligatures.[5] This difference may be

Table 4 Mean extension to tensile strength (mm) over time for all test group

	0 Hour Mean (SD)	24 Hours Mean (SD)	1 Week Mean (SD)	2 Weeks Mean (SD)	4 Weeks Mean (SD)	8 Weeks Mean (SD)	12 Weeks Mean (SD)
Orm prestr.	7.61 (0.78)	8.13 (0.38)	8.42 (0.35)	8.84 (0.56)	8.96 (0.45)	9.02 (0.45)	9.66 (0.33)
Orm clear	6.93 (0.53)	8.15 (0.32)	8.23 (0.31)	8.83 (0.27)	8.85 (0.29)	8.86 (0.26)	9.31 (0.38)
Orm blue	10.41 (0.32)	12.15 (0.35)	11.96 (0.40)	12.46 (0.44)	13.13 (0.32)	13.62 (0.31)	13.64 (0.61)
Orm green	9.81 (0.39)	11.21 (0.40)	10.98 (0.44)	12.17 (0.38)	12.25 (0.45)	12.55 (0.66)	13.52 (0.70)
Orm grey	8.92 (0.55)	10.44 (0.85)	10.88 (0.61)	11.07 (0.61)	11.41 (0.74)	11.57 (0.76)	11.77 (0.77)
Orm purple	9.06 (0.50)	10.53 (0.55)	10.83 (0.40)	11.25 (0.42)	11.52 (0.40)	11.62 (0.53)	12.48 (0.59)
Uni prestr.	9.20 (0.48)	10.17 (0.84)	9.77 (0.63)	10.49 (0.49)	10.71 (0.70)	10.83 (0.66)	11.49 (0.86)
Uni clear	8.95 (0.42)	10.03 (0.62)	9.72 (0.76)	10.22 (0.28)	10.43 (0.55)	10.57 (0.80)	10.97 (0.89)
Uni blue	8.29 (0.45)	8.61 (0.46)	8.92 (0.52)	8.81 (0.34)	9.05 (0.57)	9.59 (0.57)	9.36 (0.95)
Uni green	9.95 (0.92)	10.83 (1.21)	10.89 (1.10)	10.94 (0.72)	10.69 (0.49)	10.76 (0.53)	11.17 (0.93)
Uni grey	9.20 (0.50)	9.95 (0.73)	10.34 (0.86)	10.38 (0.47)	10.66 (1.02)	10.67 (0.34)	10.69 (0.36)
Uni purple	9.12 (0.51)	10.08 (0.65)	10.29 (0.64)	10.35 (0.74)	10.46 (0.63)	10.53 (0.49)	11.20 (0.38)

Least significant difference = 0.50 (at 5% statistical level).

Table 5 Statistical analysis of extension to tensile strength readings using ANOVA

Source	DF	Sum of squares	Mean squares	*F*-value	*P*-value
Treatments	11	783.030	71.185	61.579	<0.0001
Reps (treatments)	72	83.231	1.156		
Subtotal	83	866.262			
Time	6	280.221	46.704	208.50	<0.0001
Treatments*Time	66	52.041	0.789	3.52	<0.0001
Time*Reps (treatments)	432	96.769	0.224		
Total	587	1295.293			

attributed in part to the different brands of ligatures and/or the differences in research methodology. The strength decay characteristics of ligatures in this study are in general agreement.

The extension to TS of elastomeric ligatures was examined for the first time in this study. The significance of this characteristic is that it provides an indirect measure of the toughness of these ligatures.[2] Toughness can be measured as the total area under the force-extension curve from zero stress/force to the breaking strength. It is dependent upon both the TS and the extension to TS. Although the mean TS of the ligatures tested in this study decreased by approximately 7–22 per cent at 4 weeks, their extension to TS had increased by almost the same percentage. It can, therefore, be argued that the toughness of these ligatures remained (on average) about the same from 0 to 4 weeks.

This study collected data up to 12 weeks. It is acknowledged that in many cases elastomeric ligatures are routinely replaced at shorter intervals (usually 4–6 weeks), but there are occasions where this is not possible (when a patient cancels or fails to attend a scheduled appointment). The results of this study suggest that the small decrease in the TS observed in the ligatures between 4 and 12 weeks would not be clinically significant. Similarly, there were only small increases (in general) in the extension to TS of the ligatures between 4 and 12 weeks. The toughness of the ligatures remained stable throughout the duration of the study.

The results indicate that the Unitek ligatures tend to have higher TS than the equivalent Ormco ligatures at every time interval (except at 4 weeks for the blue ligatures). The differences became more pronounced after 24 hours. Similar results have also been obtained when the tear strength of clear elastomeric *chains* from Unitek and Ormco were evaluated over a 3 weeks period.[1] He found that the Unitek chains fractured at a slightly higher force than the Ormco chains at all but zero time intervals.

The extension to TS revealed that the Unitek clear ligatures exhibited a significantly higher extension than the Ormco clear ligatures at all times. In contrast, all of the Unitek coloured ligatures had a significantly lower extension to TS than the Ormco coloured ligatures from the 2-week stage. Wong, however, reported that the clear Ormco *chains* in his study fractured at a greater stretch, almost 100 per cent more, than the Unitek chains.[1]

The extension to TS for Unitek ligatures was not significantly different between clear and coloured ligatures except for blue Unitek ligatures which showed a significantly lower extension at every time interval. In contrast, the coloured Ormco ligatures revealed a general colour effect. The extension to TS of all the Ormco coloured ligatures was significantly higher than that of the Ormco clear ligatures (both pre-stretched and unstretched) at all times. It may be suggested that the addition of colouring material to ligatures may have a significant effect on their tensile strength properties. However, it is uncertain how this effect will be expressed clinically.

The effects of pre-stretching on the TS and extension to TS of elastomeric ligatures were also examined for the first time in this study. Clinically, ligatures are commonly pre-stretched prior to their application in certain situations. These include immediately after a bracket has been bonded (when the bond strength has not reached its maximum) or to allow easier placement of the elastomeric ligature around large brackets such as certain ceramic/plastic brackets. Both the Unitek and Ormco clear ligatures showed a slight improvement in both their TS and the extension to TS properties after gradual pre-stretching. Although this observed effect was not statistically significant at all time intervals, it is helpful to know that pre-stretching ligatures did not produce any detrimental effects.

Although the findings from this study might be a useful guide to the anticipated clinical behaviour of the elastomeric ligatures tested, caution must always be exercised when extrapolating *in vitro* findings to the clinical environment. A logical extension of this study would be to test these ligatures *in vivo*. This would allow comparison of the behaviour of these ligatures in an oral situation to determine whether the observed *in vitro* differences are clinically relevant.

Conclusions

Unitek ligatures generally exhibited a slightly greater mean TS than the equivalent Ormco ligature, and Unitek and Ormco ligatures had a similar TS decay pattern with a gradual decreased over the period of the study.

While the extension to TS increased gradually with time for Unitek clear ligatures and both Ormco coloured and clear ligatures, the Unitek coloured ligatures showed a more variable response, but the extension to TS value increased consistently from the 4-week stage onwards.

The clear ligatures of both companies did not display any detrimental effects when they were pre-stretched.

Acknowledgments

The assistance of Dr N. J. Rowell DDS (N.U.) in commissioning the test equipment is gratefully acknowledged. The authors would also like to thank the Foundation for Orthodontic Education and Research of the Australian Society of Orthodontists for its financial support.

References

1. Wong AK. Orthodontic elastic materials. *Angle Orthod* 1976; **46**: 196–205.
2. Phillips RW. *Skinner's Science of Dental Materials. Ninth Edition.* W.B. Saunders Company, Philadelphia, 1991; 29–59.
3. Young J, Sandrik JL. The influence of preloading on stress relaxation of orthodontic elastic polymers. *Angle Orthod* 1979; **49**: 104–109.
4. Callahan CE, Ramp MH, Ramp LC, Shehee GE. Tensile strength of elastomeric separators after cold sterilization. *J Dent Res* 2000; **79**: 548.
5. Dowling PA, Jones WB, Lagerstrom L, Sandham JA. An investigation into the behavioural characteristics of orthodontic elastomeric modules. *Br J Orthod* 1998; **25**: 197–202.
6. Lam TV. Force and stiffness decay of coloured orthodontic elastomeric ligatures. *[Thesis.] Brisbane, Queensland: University of Queensland. 2000*