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The effect of environmental factors on elastomeric chain and nickel titanium coil springs

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SUMMARY It is well known that elastomers exhibit viscoelasticity and as such have their mechanical properties modified by temperature. Nickel titanium archwires are also affected by temperature and have been modified with specific temperature related properties for clinical use. What is less well known is the effect that other environmental factors, such as food, might have on the force delivery properties of both elastomeric materials and nickel titanium coil springs used for space closure. For instance gross colour change in elastomeric chain is a common clinical finding in patients who consume spiced foods.

The aim of this work was to determine the effect three common environmental factors namely, water, Coke®, and turmeric solution have on elastomeric chain and nickel titanium coil springs. In addition, it was decided to re-examine the effect of temperature at 10, 22, and 37°C on both these space closing materials. Unlike many previous investigations, the test specimens were held at a constant stretch throughout the test period, including during their transfer to the Instron Universal Testing machine for force measurement. Six force measurements were made over the first hour, then at 24 hours and 7 days. A control group of dry specimens, maintained at 22°C, had additional measurements made weekly for a 4-week period.

The results indicated that elastomeric chain was affected by all the test environments while nickel titanium springs were only affected by temperature.

Introduction

In order to achieve optimal tooth movement with fixed appliances, it is accepted that a light continuous force is desirable (Proffit, 1986). Space closing systems in common use include elastomeric products, such as elastomeric chain and modules, and nickel titanium coil springs. It is well known that elastomeric products lose force over time, even under dry conditions, and that properties are modified by both moisture and temperature (Andreasen and Bishara, 1970). In the case of nickel titanium alloy, the effects of environmental factors, other than temperature, are less well known.

Previous work has assessed the force decay characteristics of many commercially available elastomeric materials, primarily measuring force decay relative to time. Elastomeric chain was introduced as an alternative to latex elastic bands and comparative studies into the force decay properties of both materials have identified some common findings. Much of the initial force is lost over the first 24 hours and then continues to decrease at a much slower, steadier rate. High initial loading forces experience greater force decay than initially lower forces, whilst moisture (saliva and water) also increases the rate of force decay (Andreasen and Bishara, 1970; Ash and Nikolai, 1978; Killiany and Duplessis, 1985; Kuster *et al*., 1986; Lu *et al*., 1993). Whilst it has been suggested that prestretching elastomeric chain before use limits the amount of force decay (Young and Sandrik, 1979), this has been found to have limited application (von Fraunhofer *et al*., 1992). Experimental testing at room temperature in dry air is clearly unrepresentative of the oral conditions in which the elastomeric chain will have to function. Attempts to simulate the oral environment have included testing in artificial saliva

(Baty *et al*., 1994), thermocycling (De Genova *et al*., 1985) and maintaining specimens in a water bath at 37ºC (Hershey and Reynolds, 1975; Ash and Nikolai, 1978). Unfortunately, these modifications have not adequately reproduced the *in vivo* state and force decay of elastomeric chain *in vivo* has been found to be far greater than in the laboratory (Ash and Nikolai, 1978; Kuster *et al*., 1986).

Nickel titanium springs have also been found to lose some of their force over time, although to a lesser extent than elastomers (Angolkar *et al*., 1992; Han and Quick, 1993). Whilst the latter were positive in their appraisal of nickel titanium coil springs, they did suggest that further research was required, for example into the effects of thermocycling and simulated mastication, before their clinical usefulness could be fully evaluated. However, Samuels *et al*. (1993) and Sonis (1994) have found nickel titanium coil springs to be more effective clinically than either a space closing module on a steel ligature or elastics, respectively.

Experimental test solutions used by other researchers have included distilled water, artificial saliva and a fluoride solution (von Fraunhofer *et al*., 1992). The effects of food on force decay have not been investigated to date.

A shortcoming common to many previous investigations has been to permit experimental specimens to relax, albeit briefly, between removal from the holding jig and transfer to the measuring apparatus. This repeated stretching and unstretching will alter the stress/strain curve because the elastic will have attained some permanent set each time it is restretched. The following investigation aimed to improve upon this problem by maintaining the specimen at a constant length for the duration of the test period. Simulation of tooth movement by progressive reduction of specimen stretch was not incorporated in this study.

Method and materials

Twenty jigs consisting of 75 × 15 × 10-mm lengths of stainless steel were constructed. Each jig carried two stainless steel posts, 20 mm long, set at 60 mm apart. Eighty hooks were constructed

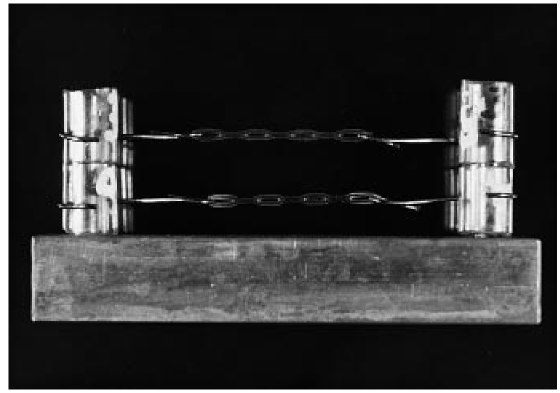

Figure 1 The customized jig used to hold the test specimens and transfer them to the Instron machine, whilst held at a constant stretch.

from 0.7-mm stainless steel wire to provide an interhook distance of 25 mm and, hence, constant stretch on the elastomeric chain or coil springs when supported on the jigs (Figure 1; Nattrass, 1996). Clear plastic tubing enabled the hooks to be slid off the jig and onto the Instron Universal Testing machine (Instron Corp., Canton, Massachusetts, USA) without any change in the interhook distance. Care was taken to ensure each pair of hooks used to support a single test specimen provided the necessary 25 mm distance when fitted onto the jigs and the plastic sleeving. Attachments were constructed for the Instron Universal Testing machine consisting of two solid pieces of stainless steel, each of which carried an adjustable rod near its base. These were attached to the load cell and crosshead, which was adjusted until the rods were 60 mm apart, i.e. the equivalent distance to the jig posts, which maintained the specimen at a constant stretch of 25 mm (Figure 2). The ambient room temperature and humidity were noted. A previous investigation (Nattrass, 1996) had demonstrated 25 mm to be the most frequent distance across which four links of medium-spaced elastomeric chain [Durachain, Ortho-Care (UK) Ltd, Bradford, UK] were applied in clinical practice. Therefore, this amount and type of chain was chosen for this experiment. The nickel titanium springs used were superelastic 9 mm closed coil 150 g springs [Ortho-Care (UK) Ltd, Bradford, UK].

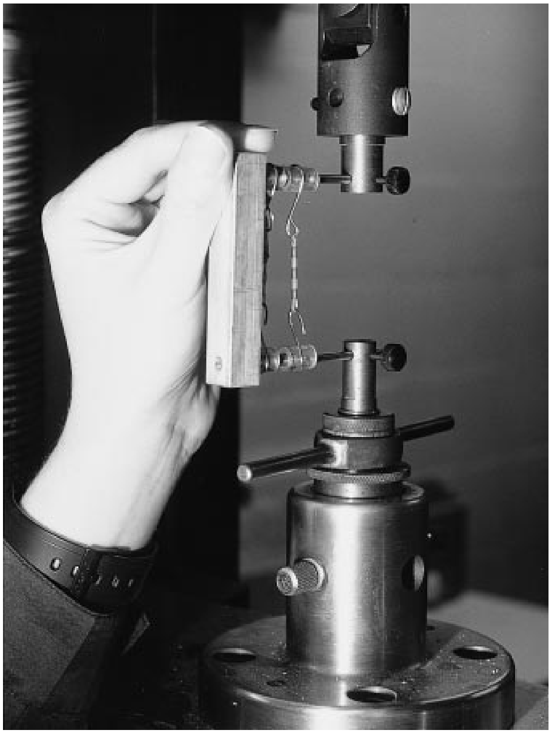

Figure 2 The customized jig held adjacent to the Instron for specimen transfer.

Ten specimens each of elastomeric chain and nickel titanium closed coil springs were selected at random from a large number of samples. Each specimen was connected to a pair of hooks (carried on plastic tubes) and stretched to a distance of 25 mm between the hooks on the Instron Testing machine. They were left undisturbed for 1 minute, whilst the residual force within the specimen was recorded. From this initial recording, the force at 0, 30, and 60 seconds was determined. A jig was then held adjacent to the Instron machine rods and the elastomeric chain, and its associated hooks and plastic tubing were then carefully fed from the machine to the jig, maintaining a constant stretch in the test specimens throughout.

Additional recordings of residual force remaining within the specimens were made in the same way at 15, 30, and 60 minutes, 24 hours, and 7, 14, 21, and 28 days. The specimens were stored dry at room temperature (22ºC) inside a box between force recordings. These specimens acted as the control group for the investigation into the effects of the environment.

This procedure was repeated, but with the elastomeric chain and nickel titanium springs being stored in one of the following solutions between force measurements:

1. Distilled water at room temperature, 22ºC.
2. Coke® (Coca-Cola Export Co., London, UK) at room temperature, 22ºC.
3. Turmeric solution (50 g of turmeric powder in 750 ml of distilled water) at room temperature, 22ºC.

The number of test specimens for this part of the experiment totalled 80, of which 40 were elastomeric chain and 40 nickel titanium springs. Coke® was used as a test substance as it is a popular drink with younger patients, and turmeric was selected because clinically, it has a profound effect on the colour of elastomers.

In each case force was measured at 8 time intervals: 0, 30, and 60 seconds, 15, 30, and 60 minutes, 24 hours, and 7 days. The experiment was then repeated with specimens maintained in water at the following temperatures for the same test period of 7 days:

(1) refrigerator at 10ºC;
(2) room temperature, 22ºC;
(3) waterbath at 37ºC.

At the beginning of each experiment the test specimens were held in the test medium for 5 seconds prior to commencement of force monitoring. After the initial force measurements had been made on the Instron Universal Testing machine, the specimens, now on the holding jigs, were replaced in their test media. In each case the specimens, on their jigs, were only removed from the test media when subsequent force measurements were made. The total number of specimens for this second part of the experiment totalled 60, 30 of elastomeric chain and 30 nickel titanium springs.

Results

Due to the difficulty of performing a statistical analysis on results which are not independent at each time interval (Matthews *et al.*, 1990) it was

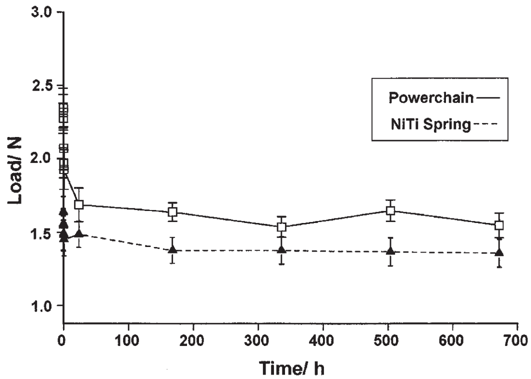

Figure 3 Mean load and 95 per cent confidence intervals as a function of time of both elastomeric chain and nickel titanium coil springs in air at a room temperature of 22°C and 60 per cent humidity (test time 28 days).

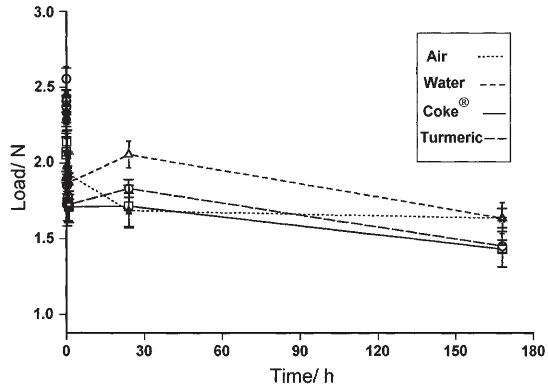

Figure 5 Mean load and 95 per cent confidence intervals as a function of time of elastomeric chain stored in four different test environments at a temperature of 22°C (test time 7 days).

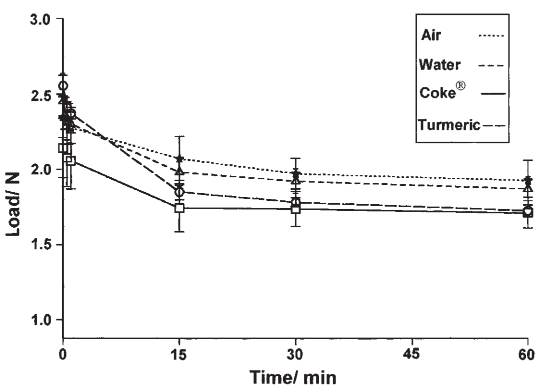

Figure 4 Mean load and 95 per cent confidence intervals as a function of time of elastomeric chain stored in four different test environments at a temperature of 22ºC. The first 60 minutes of the 7-day test.

decided to use a more pragmatic approach using means and 95 per cent confidence intervals, and to plot the values individually.

From the results (Figure 3) it can be seen that under dry conditions elastomeric chain lost substantially more force than the nickel titanium springs over the 4-week period, yet maintained a higher force throughout.

From the results of the 7-day environmental tests and turning initially to the elastomeric chain (Figures 4 and 5), it would appear from the means and 95 per cent confidence intervals over the first hour that specimens in Coke® and turmeric solution lost more of their initial loading force than specimens in air or in water. However, over the following 7 days, those in air continued to lose force up to 24 hours and then the force level plateaued over the remaining 6 days. The specimens in water and those in turmeric solution, rather unexpectedly, demonstrated increased force levels up to 24 hours which subsequently fell over the following 6 days. This was not, as might be supposed, due to experimental error as great care was taken to ensure the specimens remained at a 25 mm stretch throughout the experimental period and especially during transference to and from the Instron from the holding jigs. In the case of the turmeric specimens, the loss of force was much greater than those specimens tested in air and in water by day 7. Specimens in Coke® demonstrated the greatest force loss, and at all times the force level was far lower than specimens stored in water.

Examining the results of the nickel titanium springs, the effect of environment appeared less marked over the first hour (Figure 6) than in the case of the elastomeric chain. The difference in the force level between each of the test environments can probably be explained by the initial differences at time 0. Beyond the first 60 minutes, however, there was a marked difference between those specimens stored in air and those stored in the other three test environments (Figure 7).

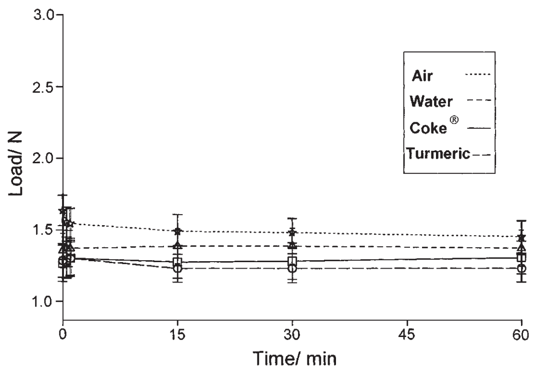

Figure 6 Mean load and 95 per cent confidence intervals as a function of time of nickel titanium springs stored in four different test environments at a temperature of 22ºC. The first 60 minutes of the 7-day test.

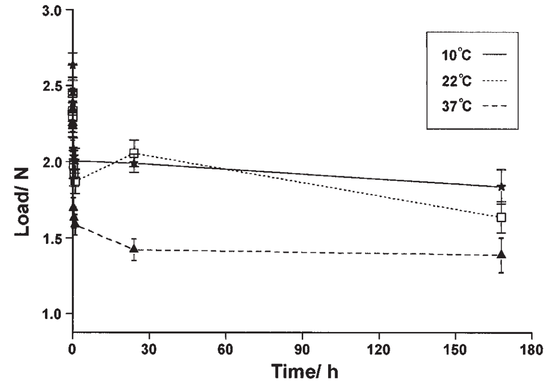

Figure 8 Mean load and 95 per cent confidence intervals as a function of time of elastomeric chain stored in water at three different temperatures, namely 10, 22, and 37°C (test time 7 days).

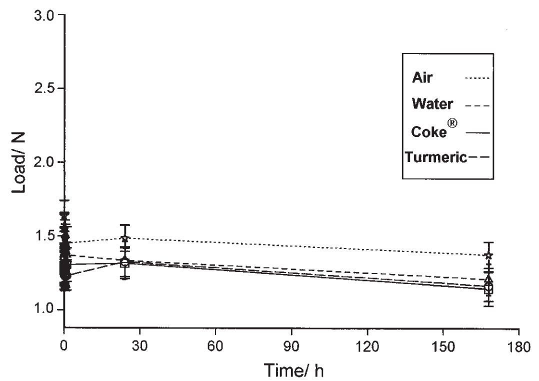

Figure 7 Mean load and 95 per cent confidence intervals as a function of time of nickel titanium coil springs stored in four different test environments at a temperature of 22°C (test time 7 days).

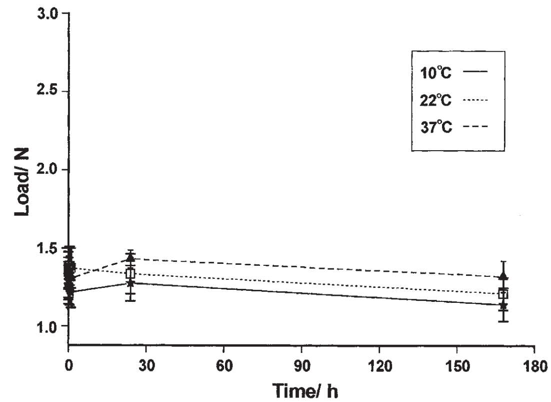

Figure 9 Mean load and 95 per cent confidence intervals as a function of time of nickel titanium coil springs stored in water at three different temperatures, namely 10, 22 and 37°C (test time 7 days).

There was little difference between the force levels over this remaining period between those specimens stored in water, Coke® or turmeric solution.

Altering temperature was found to affect both elastomeric chain and nickel titanium coil springs (Figures 8 and 9). The effect of temperature was more profound in the case of the elastomeric chain and, as would be expected from such materials, force loss was greater at higher temperatures. In the case of the nickel titanium springs, the overall effect was smaller, but nevertheless unexpectedly, force loss was greater as temperature decreased.

Discussion

The effect of food on elastomers has previously been studied by Lew (1990) in which the colouration effect produced by different foods was assessed on an analogue scale. However, no attempt was made to determine the effect such foods might have upon the physical properties of elastomeric materials. The results of this current work once again demonstrate the stress relaxation property of elastomers shown so often by other workers (Andreasen and Bishara, 1970; De Genova *et al*., 1985). In addition, Figures 4 and 5 show marked differences in the degree of force loss by elastomeric chain in the four test environments. Over the first 60 minutes (Figure 4) specimens of Coke® and turmeric demonstrated the greatest force loss and this continued until the end of the 7-day test period. Interestingly, at 24 hours, those specimens stored in water and those in turmeric demonstrated an increase in residual force and those in Coke® showed no further force loss between 60 minutes and 24 hours. The specimens in air continued to lose force up to 24 hours. It is difficult to explain the behaviour of the specimens in the test solutions up to the 24-hour test period. It is possible that following the initial and rapid force loss with stress relaxation the elastomeric chain may absorb the test solution and possibly show some increased stiffness, thereby affecting the measured force. This effect appears to be short lived with the force continuing to fall over the following 6 days. The degree of stress relaxation which will occur is finite, provided other factors do not affect the process, and this would explain why the force level of those specimens stored in air changed little after 24 hours. There was little difference between those specimens stored in air and those stored in water at the end of the 7-day test period. The notable difference between the results of those specimens tested in water, and those stored in Coke® and in turmeric suggest that some factor or factors other than water, which is present in each solution, is able to modify the physical properties of the elastomeric chain. In the case of Coke®, this could be related to the pH of the drink, which has been found to be as low as 2.01 (Ireland *et al.*, 1995). However, it is unlikely to be the complete answer, since it contradicts the work of Ferriter *et al.* (1990) who found that an acidic fluoride environment reduced the level of force decay exhibited by elastomers.

In the case of nickel titanium coil springs, the results when considered over the whole 7-day test period (Figure 7), would seem to suggest that the presence of moisture has the greatest effect on force decay and not the type of solution or food. Those specimens tested in air show little loss of force over 7 days and, indeed, little loss of force over 28 days (Figure 3). However, this effect of the test solutions may not be experimentally, let alone clinically, significant if the initial applied force at time 0 is considered (Figure 6) in each case. The results show that specimens tested in air demonstrated a higher initial force than specimens in the three test solutions. Therefore, it is possible that the observed difference is due entirely to the different starting values.

The effects of temperature on the force decay properties of elastomeric chain in this experiment (Figure 8) were similar to those reported by other workers (Hershey and Reynolds, 1975). As would be expected of a visco-elastic material, properties will be modified by temperature (Billmeyer, 1984). As temperature increases there will be a move towards the viscous fluid end of the viscoelastic spectrum, with stress relaxation becoming more pronounced. The fluctuations in intra-oral temperature on the consumption of different foods and beverages is going to be large and the results in this study would suggest that in the case of elastomeric chain, temperature is likely to be far more important than the type of food consumed. In the case of nickel titanium springs the effect is much less marked. It is interesting to note, however, that temperature has the opposite effect on the nickel titanium to that observed with elastomeric chain. As temperature rises so the measured force increases. The rate of force loss, however, is almost identical for each of the three temperatures, certainly from 24 hours up to the end of the 7-day test period (Figure 9). It is possible that the effect of temperature is due to modifications in the crystal structure of the alloy (Buehler, 1969). The effects of temperature on nickel titanium coil springs have not previously been investigated, although Angolkar *et al.* (1992) found that the force decay of NiTi springs in artificial saliva at 37ºC was 8.62–14.21 per cent over a 7-day period. This is at variance with the current investigation, in which some of the nickel titanium springs maintained in distilled water at 37ºC actually increased in residual force over the same time period.

Conclusions

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

1. Elastomeric chain was affected by both temperature and environment.
2. Whilst force decay of elastomeric chain in air was rapid for up to 24 hours, force loss between 1 and 24 hours either remained the same in the case of Coke®, or was reversed in the case of both water and turmeric solution. Thereafter, force loss continued to the end of the 7-day test period.
3. Coke® and turmeric solution had a greater effect on force loss of elastomeric chain than water alone, suggesting that some factor within the former two solutions might be modifying the properties. It is questionable, however, whether the observed effect of these foodstuffs would be clinically significant.
4. Temperature had the greatest effect on elastomeric chain. As is to be expected of a viscoelastic material, force loss increased with increasing temperature.
5. Nickel titanium coil springs were minimally affected by temperature, demonstrating a slight increase in force as temperature increased.
6. Nickel titanium coil springs were not affected by their environment. The observed differences could be accounted for entirely by the difference in initial load of the specimens under test.

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