An Evaluation of Small Diameter Orthodontic Wires

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Although archwires of .018 inch diameter and smaller have been employed for orthodontic treatment for some time there has been increased interest in their application with the introduction of the "light wire techniques". By bending these wires into different configurations it is stated that the desired amount, direction and distance of force application can be achieved.[1,2,3,5] The success of these procedures is purported to be enhanced by the use of a product marketed under the name of Australian wire.[1,4] In view of the stated success of this particular wire, it was thought desirable to determine its mechanical properties and compare these with wires of other manufacture.

EXPERIMENTAL DESIGN

Seven different manufacturer's products were tested in various designs and treatments employed in clinical application. These included four wire configurations in both a heat-treated and not heat-treated condition.

Evaluation was made by determining the two mechanical properties thought to be of greatest significance in the clinical performance of these wires: *elastic deformation/force ratio* and *elastic force limit.*

These small archwires are used principally in procedures where the objective is to achieve maximum tooth movement with a minimum of adjustment. This would require a large amount of movement with a relatively small decrease in applied force. For a given wire configuration, the mechanical property related to this requirement is the *elastic deformation/force ratio.* This ratio describes the amount of elastic deformation which occurs when a wire is activated by a given force and is constant within the elastic range of the wire configuration (a wire configuration activated within its elastic range will return to its original shape on deactivation). At the same time the elastic deformation/force ratio describes the decrease in force applied as the wire is deactivated by tooth movement. This ratio should be as large as possible to provide large movements with a relatively small decrease in applied force. To describe this property further, let us assume that two wires are activated to apply the same initial force, one wire having a *high* elastic deformation/force ratio and the other wire a *low* elastic deformation/force ratio. After the same amount of deactivation or tooth movement, the wire with the high ratio will be applying a greater force than the wire with the low ratio.

The first criterion for wire usage is the capability of delivering a specific amount of force. Several studies have been made of the amount of force required for specific tooth movements. Storey and Smith[6] have reported that the optimum range of force for retraction of the lower canine tooth is between 150-200 grams. Burstone and Groves[7] retracted anterior teeth by simple tipping and stated that optimum rates of tooth movement were observed when 50-75 grams of force were ap-

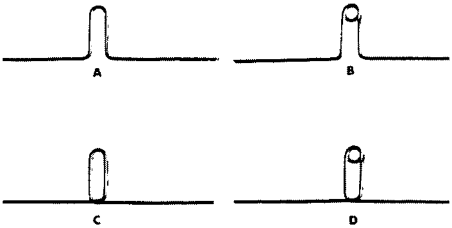

Fig. 1 Wire designs tested: A - open loop; B - helical open loop; C - closed loop; D - helical closed loop.

Fig. 2 Wire loop positioned in fixture in testing instrument.

plied. Reitan[8] has stated that the maximum force needed during any stage of a continuous bodily movement of canines is approximately 250 grams.

The mechanical property which expresses the amount of force delivered by a given wire configuration before permanent deformation occurs is the *elastic force limit* and, since bodily or translatory cuspid movement appears to require the greatest force, a wire configuration which exhibits an elastic force limit of 250 grams or more should be acceptable for all usages. Another consideration, however, would be the ability of a wire configuration to withstand forces induced by food excursion or accidental manipulation. A higher elastic force limit reflects a greater resistance to permanent deformation resulting from these conditions.

METHOD OF TEST

Design and Preparation of Test Samples — Test samples for each test condition were formed as uniformly as possible using Nance closing-loop pliers and Tweed loop-forming pliers. Each sample consisted of a straight portion, an open or closed loop, both single helical and nonhelical type loops, and another straight portion. The Nance closing-loop pliers produced an average distance between the loop legs of approximately 2 mm. The wire designs tested are shown in Figure 1. The question as to the success of this fabrication technique in reproducing a specific wire design was answered by the low variability between the mechanical property values for the ten samples run for each condition. (Coefficients of variation averaged 3.2% for the deformation/force ratio and 6.7% for the elastic force limit.)

Four stainless steel wires from different manufacturers and three cobalt-chromium alloy wires from one manufacturer were tested. Ten samples of each wire in its bent form were tested in the as-received condition, and ten additional samples were tested after being heat treated for 10 minutes at 750° F. and bench cooled immediately[9-11] (the cobalt-chromium wires were heat treated for 10 minutes at 900° F.).[12,13]

Stressing and Measuring Test Wire Specimens — The samples were stressed in an Instron tensile testing instrument which automatically records the force-deformation curve for each sample. The samples were held in the testing instrument by pin vises, the distance between the ends of the vises being 7.6 mm. The loops were stressed slightly beyond their elastic force limit. In Figure 2 is shown the fixtures in the testing machine with a wire loop in the test position.

Determining Physical Property Values — As indicated previously, it was decided that elastic force limit and elastic deformation/force ratio would be the most significant properties for evaluating these wires. The values for these properties were expressed in units which conform to those in common clinical

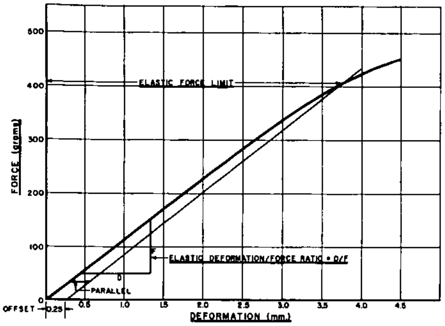

Fig. 3 Typical force-deformation curve of wire loop designs (redrawn from Instron chart recording).

use. Elastic force limit is expressed in grams of force, and elastic deformation/force ratio is expressed in millimeters per 100 grams of force. Because of the gentle slope of the force-deformation curve beyond the elastic force limit, a line was drawn parallel to the straight portion of the force-deformation curve and offset .25 mm on the deformation axis. The point where this line intersected the force-deformation curve was taken as the elastic force limit, and the elastic deformation/force ratio was taken from the slope of the original curve. A typical curve and calculation is shown in Figure 3.

RESULTS AND DISCUSSION

In Table I are shown the results of these tests. Each value reported is the arithmetic mean of ten test runs. Elastic deformation/force ratios having differences of .02 mm/100 grams and greater, and elastic force limits having differences of 60 grams and greater are statistically different at better than the 95% level using analysis of variance and Duncan's multiple range test.

The factor affecting the elastic de-

TABLE I

MECHANICAL PROPERTIES OF SMALL DIAMETER WIRES OF DIFFERENT MANUFACTURE

Wire Design

Trade Name		Open Loop		Closed Loop		Helical Open Loop		Helical Closed Loop	
		D/F[1]	F.L.[2]	D/F	F.L.	D/F	F.L.	D/F	F.L.
Australian (A)	AR[3]	.46	430	.51	740	.71	350	.85	590
	HT[4]	.44	560	.49	780	.66	610	.81	840
Oscar (B)	AR	.46	410	.51	690	.66	350	.81	570
	HT	.43	560	.48	760	.63	620	.78	810
Unitek (C)	AR	.44	450	.48	630	.70	390	.85	490
	HT	.41	600	.46	690	.64	680	.74	890
Unitek Hi-T (D)	AR	.43	530	.52	920	.67	570	.79	1060
	HT	.41	680	.46	990	.57	900	.71	1100
Elgiloy Red (E)	AR	.45	350	.53	670	.64	350	.80	510
	HT	.40	590	.41	860	.55	760	.70	910
Elgiloy Green (F)	AR	.46	300	.49	550	.70	280	.87	420
	HT	.38	490	.41	770	.57	560	.75	650
Elgiloy Yellow (G)	AR	.40	290	.44	410	.64	300	.81	370
	HT	.36	420	.40	620	.55	460	.69	600

[1] Elastic Deformation/Force Ratio, expressed in mm/100 grams force
[2] Elastic Force Limit, expressed in grams
[3] AR -- as received
[4] HT -- heat treated
[5] Differences in D/F values of .02 mm/100 gms force and greater are statistically different at better than 95% confidence
[6] Differences in F.L. values of 60 grams and greater are statistically different at better than 95% confidence

formation/force ratio to the greatest extent is the design of the wire. Increasing the number of loops exhibits the most dramatic increase in this ratio and the closed loop is more efficient than the open loop in this regard. This duplicates the findings of Burstone et al.[2] In addition, increased number of loops does not lower the elastic force limit to any great extent (see open loop vs helical open loop and closed loop vs helical closed loop).

Heat treatment increases the elastic force limit appreciably, particularly for those designs involving more loops. Whether this increase is necessary or not is a question to be answered by future investigation, since in all instances none of the elastic force limits of any combination of wire type, design or heat treatment investigated in this study fell below 250 grams (a force presumably greater than that required of these light wires.) In general, the elastic deformation/force ratio is lowered slightly by heat treatment, but the significance of this is speculative.

Another point to be considered is the relatively large elastic force limits recorded. There may be some hazard in applying too great a force by overactivating one of these loop designs. For example, if a helical closed loop were to be used and a 250 gram force for cuspid retraction was indicated, then the amount of activation for a wire with an elastic deformation/force ratio of .87 mm/100 grams should not exceed 2.50 x .87 = 2.2 mm.

For a comparison of manufacturer's products, the data for the helical closed loop are plotted in bar graph form in Figures 4 and 5. In Figure 4 is shown the variation in elastic force limit where heat treatment increases this property appreciably in most cases. Unitek Hi-T (D) has the highest values in both the as-received and heat-treated conditions. Australian (A), Oscar (B), Unitek (C) and Elgiloy-red (E) are next highest and have comparable values while Elgiloy-green (F) and Elgiloy-yellow (G) have somewhat lower values. However, the maximum force of 250 grams, indicated in this figure, is far below even the weakest wire.

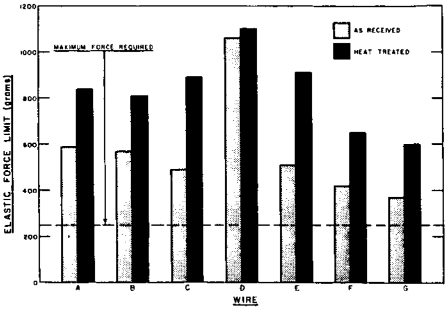

Fig. 4 Elastic Force Limit of wires of different manfacture, helical closed loop design.

In Figure 5 is shown the elastic deformation/force ratios of all the wires. The Australian wire (A) exhibits a high elastic deformation/force ratio. This mechanical property correlates well with the reported clinical success of this wire. However, the other wires tested also exhibit relatively high values for this property. Some are as high as the Australian wire (A), others slightly lower.

To attach some meaning to differences in elastic deformation/force ratio, let us compare two wires in Figure 5,

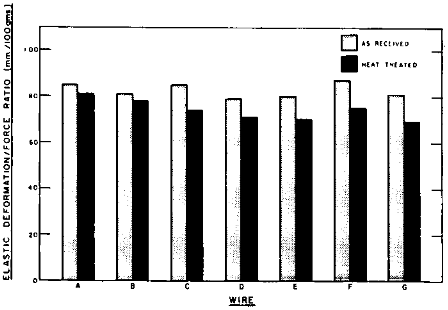

Fig. 5 Elastic Deformation/Force Ratio of wires of different manufacture, helical closed loop design.

one having the highest and the other the lowest ratio (as-received condition). Wire F has a ratio of .87 mm/100 grams and wire D has a ratio of .79 mm /100 grams. The analysis would be as follows: For an activation force of 250 grams, wire F would have a working distance of 2.2 mm compared with 2.0 mm for wire D. After 1.0 mm of deactivation, wire F would be applying a force of 138 grams compared to 124 grams for wire D. It would be speculative to attach clinical significance to these differences.

SUMMARY AND CONCLUSIONS

In this investigation the significant mechanical properties of different types of small diameter orthodontic wire when bent into loops of various configurations were determined as well as the effects of heat treatment. *Elastic deformation/force ratios* and *elastic force limits* were compared. In view of the specific requirements of this type of wire, the following conclusions appear evident:

1. All wire types, designs and conditions tested produced elastic force limits in excess of that apparently required of light wire applications.

2. Wire design has the greatest influence on the significant working characteristics of a light wire appliance. Increased number of loops and the closed loop in preference to the open loop provide an increase in the elastic deformation/force ratio which is most desirable.

3. Heat treatment increases the elastic force limit appreciably in most cases but decreases, slightly, the elastic deformation/force ratio.

4. Wires of other manufacture compare favorably to Australian wire and should be equally successful in light wire techniques.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. D. H. Carson for suggesting this investigation and to Dr. E. H. Hixon for editing the manuscript. Data were programmed by Dr. K. H. Lu, Head of the Department of Biostatistics, University of Oregon Dental School and run by Western Data Processing Service.

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