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Evaluation of stress-relief methods on cobalt-chromium orthodontic wires

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Abstract

Stress-relieving heat treatment is reported to accelerate the elastic memory process in order that the configuration of cold-worked orthodontic wires becomes more stable. In this experiment, 3 methods of stress-relieving 0.036-inch cobalt-chromium orthodontic wires used in the fabrication of space-maintaining appliances were evaluated. The results showed that stress relief in a dental oven, by the electric current of an orthodontic spot welder or by the flame of a dental soldering unit, does appear to accelerate the expression of elastic memory in cold-worked, cobalt-chromium wires. However, after an initial deformation, the stress-relieved wires tended to stabilize while untreated wires continued to deform. The experiment reinforced the need to check stress-relieved wires and appliances before inserting them into the mouth and to reshape them as required.

When an orthodontic wire is bent, internal stresses are created within that wire. These stresses are created by irregularities in the atomic lattice structure and may cause the newly shaped wire to deform and seek its original shape. This progressive change in shape is known as elastic memory and may result in unwanted tooth movement. At ordinary room (or body) temperatures, elastic memory is a gradual process. Stress-relieving heat treatment accelerates the elastic memory process so that the wire becomes more stable (Thurow 1982; Phillips 1982).

The effects of heat treatment on the physical properties of cobalt-chromium orthodontic wires, such as flexural yield strength, modulus of stiffness, fracture resistance, hardness, etc. are well documented (Mahler and Goodwin 1967; Martin et al. 1984). However, little research has dealt directly with the dimensional stability associated with stress-relieving heat treatment. Durr et al. (1986) showed that 3 common methods of stress-relieving heat treatment using a dental oven, electric current, or a soldering flame, did not reduce the dimensional change which occurred in *U*-shaped 0.036-inch cobalt-chromium orthodontic wires as compared to nonstress-relieved wires. However, almost all of the dimensional change occurring in the experimental groups took place during the stress-relief treatment after which there were only insignificant changes. Dimensional changes in nonstress-relieved wires continued throughout the 4-week experimental period. The experiment demonstrated that the 3 methods of stress relief accelerated the elastic memory process. However, the *U*-shaped wires used in the study were not soldered to orthodontic bands, nor were they heat treated on working casts. Thus, the experiment did not accurately represent procedures commonly used to fabricate interceptive orthodontic or space-maintaining appliances. The purpose of the present study was to evaluate the same 3 methods of stress relief on 0.036-inch, cobalt-chromium orthodontic wires under conditions which more accurately reflect clinical use.

Materials and Methods

Cobalt-chromium 0.036-inch-diameter orthodontic wire (Blue Elgiloy® — Rocky Mountain Orthodontics; Denver, CO), all from the same batch, was cut into 80 pieces, each 10.0 cm in length, using a jig and wire nippers. The wires were bent to a *U*-shaped form using finger pressure and an edgewise arch former (Rocky Mountain Orthodontics; Denver, CO) and then soldered to orthodontic bands which were stabilized on jigs (Fig 1, next page). The outermost width of each *U*-shaped wire was measured immediately after soldering with the wire still on the jig (coded as "baseline" measurement). Measurements were made to the nearest 0.1 mm using a Boley gauge (Fig 2, next page).

The 80 wires were divided into 4 groups each containing 20 wires:

Group A — *Untreated Control Group.* These wires were removed from the jigs after soldering and initial measuring, immediately remeasured with the Boley gauge

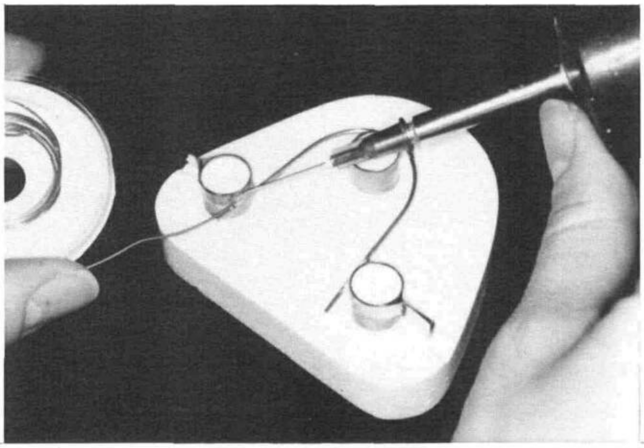

FIG 1. *U*-shaped 0.036-inch cobalt-chromium orthodontic wire soldered to orthodontic band material on jig.

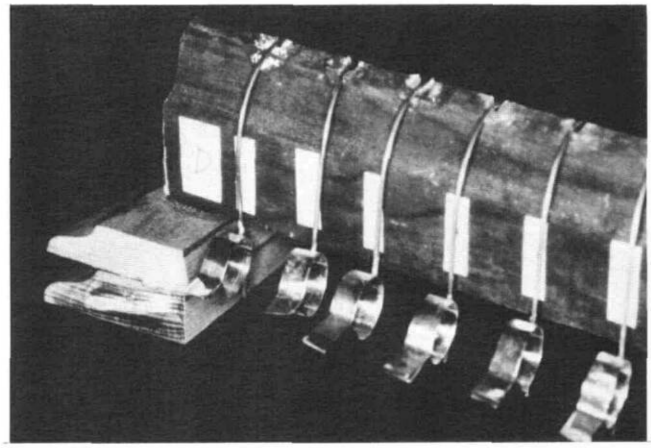

FIG 3. Storage rack for hanging wire during experimental period.

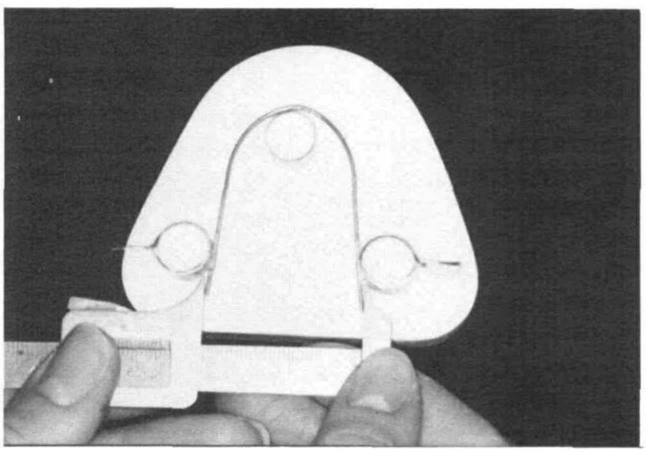

FIG 2. Outermost width of each *U*-shaped wire measured with Boley gauge.

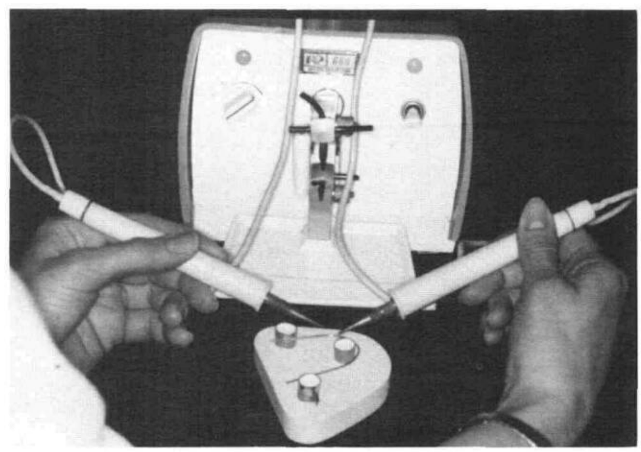

FIG 4. Stress-relieving heat treatment using electrodes of an orthodontic spot welder.

(coded as "off-jig" measurement), and then placed on a storage rack (Fig 3).

Group B — *Oven-Treated Experimental Group.* These wires were kept on the jigs and placed in a previously calibrated dental oven (Ney-Barkmeyer model 260 — J.M. Ney Co; Bloomfield, CT) at 950° F for 8 min as per a method described by the manufacturer of the wire.

Group C — *Electrode-Treated Experimental Group.* These wires were stress relieved on the jigs using the electrodes of an orthodontic spot welder (Model 660 — Rocky Mountain Orthodontics; Denver, CO), according to the directions accompanying the spot welder. The standardized method was to stress relieve short segments of wire (Fig 4), each segment being about one-fifth of the total length of the wire, for about 8 sec and then to proceed on to the next segment. Temper-indicating paste (Rocky Mountain Orthodontics; Denver, CO) which ignites at 950° F was used to show when the desired temperature was achieved.

Group D — *Flame-Treated Experimental Group.* These wires were stress relieved on the jigs using the flame of a dental soldering unit (Hydroflame® — Unitek Corp; Monrovia, CA). The temper-indicating paste was placed on the wire, and the flame was passed over the wire at a uniform distance of 1.0 cm (Fig 5) until the paste ignited, indicating that the proper temperature of 950° F for stress relief had been reached.

Immediately after the stress-relief treatment, wires in the experimental groups were remeasured on the jigs (coded as "post-tx" measurement), then removed from the jigs, measured again (coded as "off-jig" measurement), and placed on storage racks.

The wires in all 4 groups were remeasured after: 1, 2, 3, and 4 hr; 1, 2, 3, 4, 5, and 6 days; and 1, 2, 3, 4, 5, and 6 weeks. These time intervals were chosen on the basis of the results of the earlier experiment by Durr et al. (1986).

At the end of the 6-week observation period, the forces generated by the lateral expansion of the *U*-shaped wires were measured using a dial tension gauge (Model AG30 — John Chatillon & Sons Inc; New York, NY) to deflect the wires back to their baseline widths. Then the wires were readjusted to their baseline widths. Expansion after readjustment was measured at 1-day and 1-week intervals.

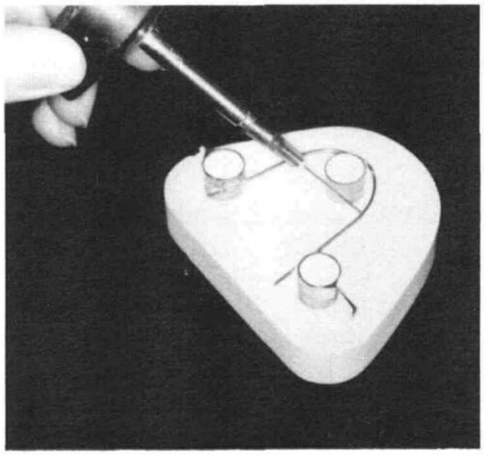

FIG 5. Stress-relieving heat treatment using flame of dental soldering unit.

Summary statistics were calculated for the control and experimental groups at each time interval. An analysis of covariance followed by multiple comparisons testing was used to investigate treatment differences over time. These comparisons were based on the least square means which differ from raw means in that they are adjusted for any differences that may exist among baseline widths of the *U*-shaped wires (Winer 1971). Statistically significant differences were reported if P values less than 0.05 were found.

Results

Mean widths and standard errors for the 19 measurement intervals of the initial 6-week experimental period were calculated, and for simplicity these data were collapsed into 4 representative epochs: (1) from baseline to off-jig; (2) from off-jig to day 1; (3) from day 1 to week 1; and (4) from week 1 to week 6. Epoch 1 included the stress relieving heat treatment for the experimental groups.

Table 1 lists the mean width changes across the 4 selected epochs along with the results of analysis of covariance and multiple comparisons testing. During the first epoch, wires in the oven-treated (B) group showed significantly greater width increases than did wires in the other 3 groups. During the second epoch, the control (A) group had significantly larger changes than the other 3 groups. There were no significant differences among the groups in the third epoch, but in the fourth, the control (A) and flame-treated (D) groups demonstrated the greatest change.

Figure 6 graphically demonstrates the dimensional changes which occurred over time. Most of the expansion of the experimental groups (B, C, D) was manifested immediately after the stress-relief procedure at the time the wires were removed from the jig. After this initial expansion, the widths of wires in the oven-treated (B) group stabilized, and those in the electrode-treated (C) and flame-treated (D) groups increased only slightly. In the control (A)

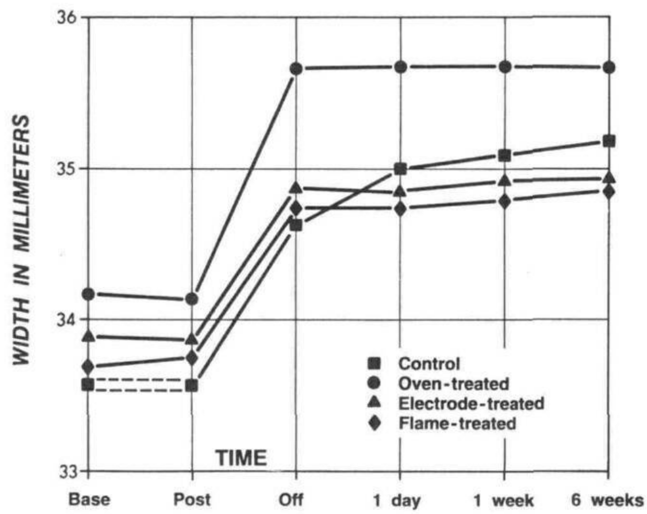

FIG 6. Comparison of stress relief methods on cobalt-chromium orthodontic wires.

TABLE 1. Width Changes Among Experimental and Control Groups Across Four Selected Time Epochs

Epoch	*Group A Control*	*Group B Oven-Treated*	*Group C Electrode-Treated*	*Group D Flame-Treated*	*p-Value from Analysis of Covariance*	*Multiple Comparisons Groupings*[b]
1. Baseline to off-jig	1.04 (0.13)[a]	1.49 (0.16)	0.98 (0.12)	1.04 (0.12)	0.01	(C,A,D) (B)
2. Off-jig to day 1	0.38 (0.05)	0.01 (0.01)	−0.03 (0.05)	0.00 (0.02)	< 0.0001	(C,D,B) (A)
3. Day 1 to week 1	0.08 (0.02)	0.00 (0.00)	0.07 (0.06)	0.05 (0.02)	0.29	(B,D,C,A)
4. Week 1 to week 6	0.09 (0.02)	−0.01 (0.01)	0.01 (0.02)	0.08 (0.01)	0.0008	(B,C) (D,A)

[a] Mean (standard error).

[b] Ordered from least to greatest change; parenthetical groups are significantly different from each other; groups within parentheses are not significantly different.

group, a substantial amount of expansion was evident at the time the wires were removed from the jig. This was followed by an increase during day 1 which exceeded that seen in any of the experimental groups to a statistically significant degree. From day 1 to week 6, the wires in the control group continued to expand, and although the expansion over the final 2 epochs was slight, it was greater than that seen in any other group.

Table 2 shows the lateral forces associated with total width changes of the wires at the end of the 6-week experimental period. The mean grams of force and standard errors are reported along with the results of a Pearson product moment analysis which demonstrate significant positive correlation between the amount of force generated and the amount of wire expansion.

Table 2. Lateral Forces Associated With Total Width Change of Wires After Six Weeks

	Width Change (mm)	*Force (g)*	r^b
Group A: control	1.60 (0.15)[a]	16.58 (1.56)[a]	.94
Group B: oven-treated	1.49 (0.15)	13.91 (1.55)	.92
Group C: electrode-treated	1.04 (0.11)	11.18 (1.06)	.96
Group D: flame-treated	1.16 (0.12)	12.84 (1.00)	.96

[a] Mean (standard error).
[b] Pearson Product Moment correlation.

Only 10 of the 20 wires in the control (A) group, 6 in the oven-treated (B) group, 6 in the electrode-treated (C) group, and 11 in the flame-treated (D) group exhibited width changes 1 day and 1 week after readjustment to baseline measurements. Mean width changes for the groups were in the 0.05-0.12 mm range. No further statistical analyses were performed on these data because more than half of the wires exhibited no additional dimensional change after readjustment.

Discussion

The results of this experiment, along with those of a previous study (Durr et al. 1986), demonstrate that stress-relieving heat treatment appears to be associated with acceleration of the elastic memory process in 10.0-cm long, 0.036-inch diameter cobalt-chromium orthodontic wires used in fabrication of interceptive orthodontic appliance.

Wires in the experimental groups exhibited almost all of their width change when they were removed from the jigs following soldering to the orthodontic bands and stress relief, but tended toward stabilization with little or no dimensional change thereafter. Wires in the oven-treated group seemed to have the most initial expansion associated with the stress-relief procedure and the least amount of subsequent expansion.

Wires in the untreated control group also showed a substantial expansion when they were removed from the jig following soldering to the orthodontic bands. Unlike the wires of the experimental groups, these wires also exhibited a significant width change during day 1. Subsequent expansion from day 1 to week 6 was slight but was greater than that seen in any of the experimental groups.

The lateral forces generated by the expansion of the wires ranged from 1.0 to 32.8 g with the greatest forces being associated with those wires exhibiting the greatest amount of expansion. These forces are clearly within the range capable of causing undesirable lateral movement of abutment teeth (Weinstein 1967).

Readjustment of the wires to their baseline measurements showed that a majority of the wires, even those in the control group, remained stable at the readjusted dimension for 1 week. Those wires that did re-expand did so to a much lesser extent than that seen after the initial bending. Much of the re-expansion occurred during the first day following readjustment. An observation made during this part of the study was that those wires which were overcompressed and then expanded slightly to meet baseline measurements seemed to exhibit the least subsequent change.

The fact that wires in the control group remained stable after being readjusted suggests further study. It may be possible that untreated appliances can be overcompressed immediately after fabrication and removal from the working cast, expanded to meet baseline measurements, and then remain stable. If feasible, stress-relieving heat treatment may not be necessary, although heat treatment to alter other physical properties, such as hardness, still may be desirable.

It must be noted that the results of this experiment are specific for appliances fabricated from 0.036-inch diameter cobalt-chromium orthodontic wires approximating 10.0 cm in length. Wires of other diameters, configurations, and/or lengths may react differently to stress-relieving heat treatment procedures.

Summary

The procedures used in this experiment parallel those used in the fabrication of a fixed space-maintaining appliance using cobalt-chromium orthodontic wire. The results show that the immediate deformation of such appliances related to stress-relieving heat treatment may approach that encountered by untreated wires over time. After the initial deformation, the heat-treated wires tend to stabilize and untreated wires continue to expand. The forces generated by such defor-

mation may be sufficient to cause unwanted movement of abutment teeth. Thus, the experiment reinforces the need to check stress-relieved orthodontic wires and appliances before inserting them into the mouth and to reshape them as required. Very little dimensional change appears to be associated with the readjusted wires.

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