Commentary

This paper reports the outcome of an experimental program in which continuous force-versus-deformation data was collected from a sample of helical-coiled orthodontic springs. From the individual plot generated during a test, the range of the linear portion of the force-deformation relationship and the slope of that portion, the stiffness or spring constant was determined. The independent, controlled variables were the material of the spring wire, the wire diameter, the inside diameter of the coil (lumen size), passive coil configuration (closed or open; "hooks" bent into segment ends or not), and whether or not a specific heat treatment was undertaken after specimen preparation and prior to testing. Segments were cut from spooled, continuous spring lengths; a constant was the passive length of the prepared spring. Parameters not controllable by the authors, but assumed constant within subsamples were wire resilience, the pitch angle of the coils (90 degrees minus the angle between coils and the longitudinal axis of spring), the passive distance between coils, and manufacturing processes.

Principal subsamples were non-heat-treated, closed-coiled springs loaded in uniaxial, longitudinal tension, non-heat-treated, open-coiled springs activated in axial compression, and heat-treated closed- and open-coiled springs of one wire material (Elgiloy) subjected to tension and compression, respectively. Linear-range and stiffness magnitudes from individual specimens were subjected to analyses of variance; interpretations of outcomes followed, and comparisons were made with range and stiffness values previously published. The experiment was well designed for its primary purpose: to provide practitioners with up-to-date, clinically useful, parametric data for a spectrum of commonly used orthodontic springs. The numbers of replications were apparently sufficient to ensure statistically interpretable results.

The parametric values generated in this bench study are the products of three or four superimposed sets of processes. First, the wire is manufactured through the series of rolling, drawing, and heat-treatment protocols that partially impart the resulting structural-characteristic values. Second, the spring is wound through an extended inelastic bending procedure. The wire emerges from both steps with induced residual stresses, likely distributed nearly if not completely throughout the entire cross-section as well as its length; the "locked-in" stresses in perhaps an axisymmetric pattern after wire manufacture become asymmetric with the fabrication of the spring. Third, the residual stresses are redistributed and, perhaps, lessened through the heat-treatment, if undertaken. Fourth, the spring is loaded or activated; the overall uniaxial deformation is achieved virtually entirely through a combination of elastic bending and twisting of the spring with the latter dominating. Transverse and circumferental elastic shearing stresses in particular are superimposed on the aforementioned residual stresses. Longitudinal compressive loading of a coiled spring induces the two patterns of shearing stresses, each opposite in sense to its counterpart produced by uniaxial tension.

To a substantial extent, the magnitude of the spring constant in this experiment was found to follow in its variance the theory that assumes exclusive torsional deformation of the spring wire in activation; the longitudinal force-deformation ratio hypothetically depends directly upon the modulus of rigidity of the wire material and the fourth power of the wire diameter and inversely upon the number of active coils and the third power of the lumen size (Popov: *Introduction to the Mechanics of Solids,* Prentice-Hall, 1968). The elastic constants of the two wire materials represented in the experiment are of comparable magnitudes. The lumen sizes marketed differ only slightly; not intended is to produce a variance in stiffness values, but, rather, to accommodate as "cores" typical "working" sizes of (rectangular) wire to ensure stability (inconsequential lateral deflections with compressive spring activations). The range of stiffness magnitudes was achieved, primarily, by

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-06-13 via free access

variances in the wire diameter and the number of active coils in the spring (the latter directly related with lumen size to the overall curvilinear length of wire in the spring).

In straight-wire orthodontic (elastic) bending and torsion, the practitioner may freely select material and cross-section within bounds; the length parameter that also influences stiffness is controlled in large part anatomically. The concept of a "unit" bending or torsional stiffness is known to the civil engineer; this parameter is the product of the material and cross-sectional influences. The length contribution is an inverse one; the greater the length, the more flexible the member. The "unit stiffness" concept is also appropriate for the spring, and the inverse proportion of stiffness to longitudinal dimension is made clear by a mechanics analysis; a common value of axial force is carried through each unit length and the entire length of the spring. The internal force is the same within each unit segment of the spring while the deformations of the segments are equal and additive; hence, the overall flexibility of the spring is directly proportional to the spring length as concluded by the author(s). Again, the practitioner is often subjected to constraints on length, and may be required to select values of other spring-stiffness-influencing parameters to accommodate passive and/or activated length restrictions.

Structural engineering teaches that the tensile and shear moduli of homogeneous metallics are dependent only upon the chemical composition of the materials. Effectively assumed in the word "homogeneous" is the virtual absence of residual stresses, and the assumption is generally valid for relatively large cross-sections. Such is not the case with small-diameter wires, however. Published papers on bending stiffnesses of archwire and auxiliaries formed from archwire segments (e.g.: Lane and Nikolai, Angle Orth., 50:139-45, 1980; and Asgharnia and Brantley, Am. J. Orthod. Dentofac. Orthop., 89:228-36, 1986) have suggested that the distributed residual stresses left by manufacturing processes and subsequent fabrication (e.g., into springs) impact stiffness. Moreover, related to the asymmetry of the residual-stress patterns, the direction of (elastic) activation related to the direction of the preceding inelastic deformation to produce the desired geometry (of a "loop" or spring) has been found to affect stiffness. In addition, stress-relief heat-treatments, inasmuch as they reduce the intensities and alter the patterns of residual stresses, influence wire-stiffness values.

To summarize, then, in the experiment under discussion, the principal influences on stiffness variance, as well as on that of the upper bound of linear portion of the force-deformation plot (approximately the elastic limit), were the wire diameter, the amount (curvilinear length) of wire in the spring, and the residual stresses. (The initial nonlinear portion of the plot was also likely a direct result of the presence of residual stresses.) Unequal stiffnesses, tensile versus compressive activation of alike springs is residual-stress based. The heat-treatment of the Elgiloy-wire springs not only altered and partially relieved the "locked-in" stresses of manufacture/fabrication, but also increased the (surface) hardness of the wire and its resilience —elongating the linear portion of the force-deformation diagram in tension. Differences in stiffness values for apparently the same spring, these research results versus previously published data, likely are indicative of recent changes in manufacturing and/or fabrication protocols that are reflected in the patterns and distributions of residual stresses. Once again, the objective of the research for this article was to generate clinically useful, current data on orthodontic springs for the practitioner; the author(s) have accomplished that objective.

—Robert J. Nikolai, PhD
Professor of Biomechanics
St. Louis, Missouri

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-06-13 via free access