Force generation by orthodontic coil springs

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Efficient, biological tooth movement by means of light continuous forces is the preferred treatment modality in contemporary orthodontics,[1-5] typically achieving tooth movement in the range of 0.5 mm/wk for a short time with light continuous forces in the range of 75 - 100 g.[5] However, many of the established methods of moving teeth are less than optimal in terms of efficiency and practicality. Thus movement of teeth is achieved by introducing loops into stainless steel (SS) wire but, because of the high load/deflection rate inherent to stainless steel, the movement is of low efficiency, requiring frequent activations. The load/deflection rate may be reduced through change of archwire, e.g. ß-titanium, but there are accompanying disadvantages such as an increase in frictional resistance between the wire and bracket. There is also increasing interest in nickel-titanium (Nitinol or NiTi) alloy wires, particularly in clinical situations requiring low-stiffness wires with an extremely large springback.[6]

The use of coil springs as an alternative to archwires for orthodontic tooth movement has been proposed by many workers. Although the concept of NiTi coil springs was suggested in 1975,[7] the clinical usefulness of such springs was not reported until much later.[8,9] There is very little in the literature on the orthodontic application of nickel-titanium springs and this study was undertaken to characterize the force delivery behavior of NiTi coil springs.

Abstract

Nickel titanium (NiTi) coil springs are a new development in orthodontics, designed to produce light continuous forces. This study compares the force delivery by NiTi open and closed coil springs during unloading (de-activation) to that provided by comparable stainless steel (SS) springs.

Open-coil springs (0.010x0.035 inch) were compressed from their initial length of 15 mm to 6 mm and the forces generated with spring recovery recorded. Closed-coil springs (0.009x0.035 inch) were distracted from their initial length of 3 mm to 9 mm and the force recorded as the spring recovered.

The closed-coil NiTi springs produced light continuous forces of 75-90 g over the distraction range of 6 mm while the open-coil springs produced forces of 55-70 g within the 9 mm compression range. SS springs produced heavier forces, ca. 200 g, for an activation of 1mm and the generated force increased rapidly as the activation was increased. The findings indicate that NiTi coil springs deliver optimal forces for orthodontic tooth movement over a longer activation range than comparable SS springs.

Key Words

Nickel-titanium • Coil springs • Force generation

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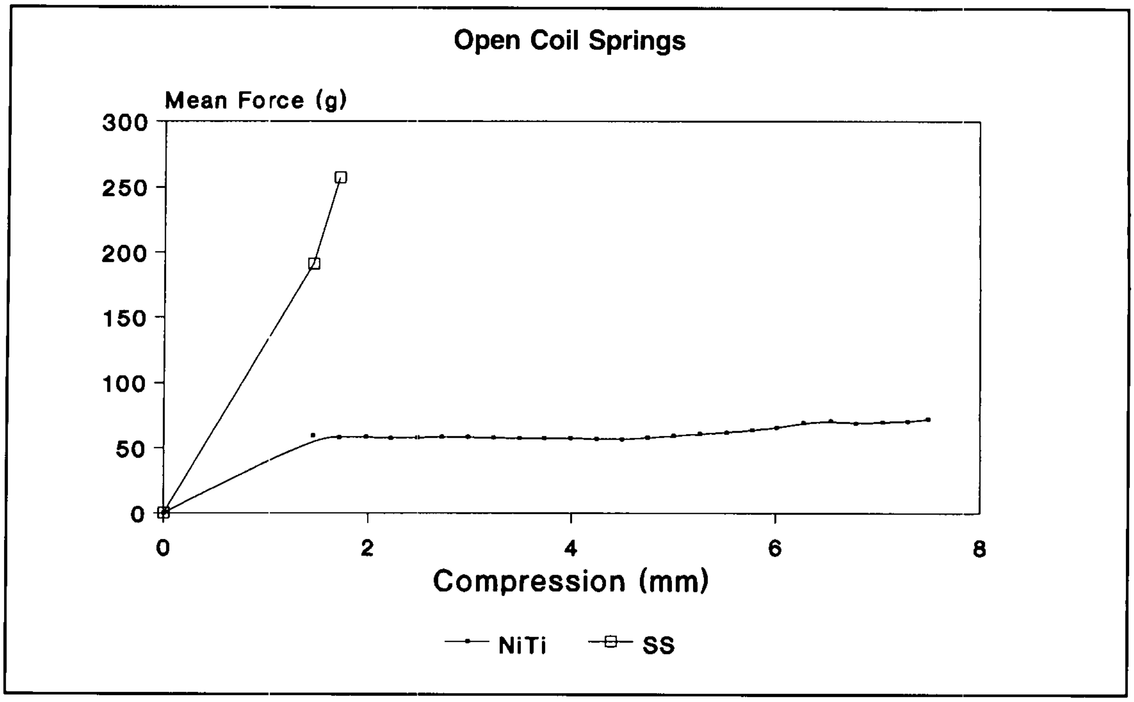

Figure 1
Force-compression behavior of nickel-titanium and stainless steel open-coil springs during de-activation (unloading).

Materials and methods

Six nickel-titanium open-coil (0.010" x 0.035") and 6 NiTi closed-coil (0.009" x 0.035") springs (Sentalloy^{TM}, GAC International, Central Islip, New York) were used in this study to determine the force produced as a function of displacement. The open-coil springs were tested in compression and the closed-coil springs in distraction with their behavior compared to stainless steel open-coil and closed-coil (0.010" x 0.030") springs (Hi-T Coil Springs, Unitek Corporation, Monrovia, Calif.).

An Unite-O-Matic FM20 universal testing machine (United Calibration Corp., Garden Grove, Calif.) was used to measure the force produced by both groups of springs with the forces generated and the distance the crosshead traveled automatically recorded by the internal chart recorder of the tensometer. The open-coil springs were tested in compression and the closed-coil springs in tension.

The open-coil springs were placed over a conical stainless steel rod of decreasing diameter (0.91 to 0.70 mm) centered in a metal plate secured to the base of the FM-20 universal testing machine. When moved downward, the crosshead applied force to the larger diameter end of the rod and compressed the spring. The closed-coil springs were suspended between pairs of U-shaped metal brackets attached to the base and movable crosshead of the testing machine such that the springs were distracted as the crosshead moved upwards.

The open-coil springs were compressed at a rate of 2.5 mm/min from the initial length of 15 mm (NiTi) or 12 mm (SS) to 6mm. Then the crosshead movement direction was reversed and the springs were unloaded back to the initial length at the same crosshead rate. Since it is the force produced after the spring has been compressed (activated) that is of clinical relevance, only the forces produced during the unloading (de-activation) cycle were analyzed. Stress relaxation behavior was assessed by applying a load to the spring and compressing it by 9 mm. The load was then reduced, and the spring was allowed to return to 7 mm compression. Crosshead movement was then stopped and the force generated by the spring at this compression was measured for 30 minutes. The spring was then deactivated in 1 mm increments down to 3 mm compression and the force measured for 30 minutes at each increment to determine the force decrease as a function of time.

The closed-coil springs were distracted from their initial length of 3 mm to 9 mm and unloaded back (de-activated) to the initial length at a rate of 2.5 mm/min. Since only the force produced during unloading of the distracted spring is clinically relevant, analysis of the generated forces was restricted to the unloading cycle. Stress relaxation was evaluated by distracting a spring by 6 mm, reversing the direction of crosshead movement and allowing the spring to return to 4 mm distraction at a rate of 2.5 mm/min. The crosshead was then held stationary while the force was measured for 30 minutes. Thereafter, the spring was returned to its initial length at a rate of 2.5 mm/min.

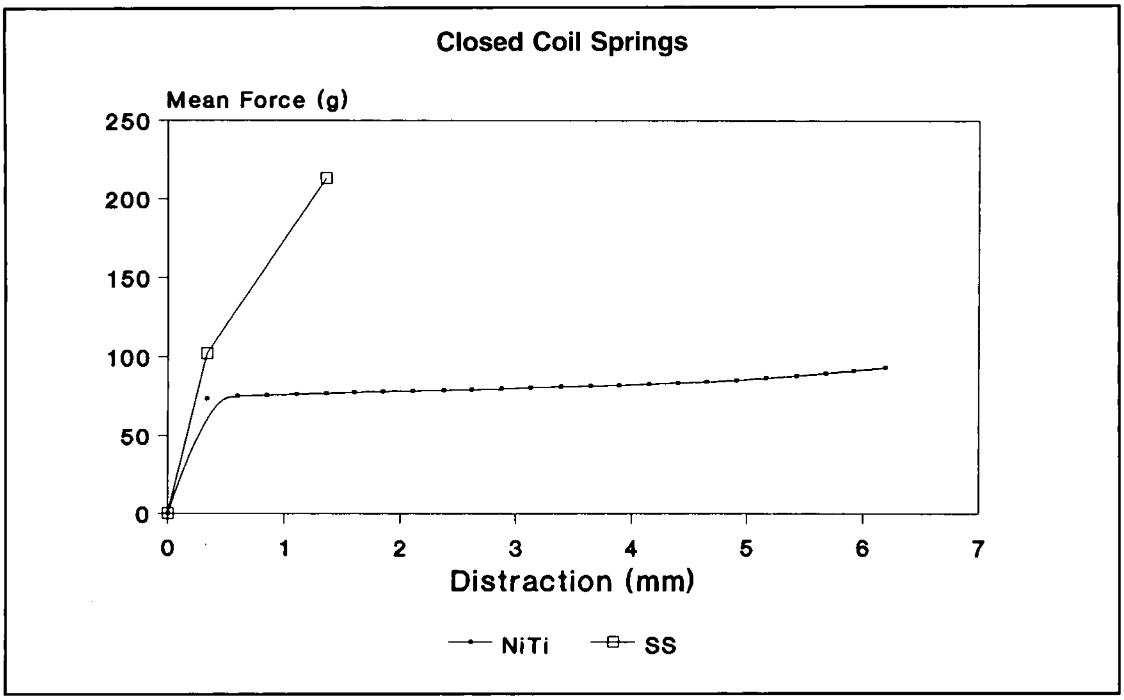

Figure 2
Force-compression behavior of nickel-titanium and stainless steel closed-coil springs during de-activation (unloading).

Each plot produced by the internal chart recorder was digitized and the data represented graphically as force versus length of the extended or compressed spring.

Results

The force-compression/extension curves for NiTi and stainless steel coil springs during unloading (de-activation) are shown in Figures 1 and 2. The open-coil nickel-titanium springs produced a mean force of 61.7±5.2 g during unloading over an activation range of ca. 7 mm, Figure 1. In contrast, the force delivered by stainless steel open-coil springs decreased from 257 to 191 g with a change of only 0.3 mm in activation. Thereafter, there was a linear decrease in delivered force over the compression range of 1.5 to 0 mm.

The stainless steel closed-coil springs produced high forces during unloading that decayed rapidly as the extension was reduced while the NiTi closed-coil springs produced a mean force of 81.7±3.3 g over the distraction range of ca. 6 mm, Figure 2.

Neither the stainless steel nor the nickel-titanium open- and closed-coil springs showed any significant stress relaxation over their respective ranges of activation although the range of activation for the nickel-titanium springs was much greater than that of the stainless steel springs.

Discussion and conclusions

The nickel-titanium open-coil springs were found to produce light, continuous forces through a long range of activation although the forces produced were slightly below the optimum 75-100 g range. The closed-coil NiTi springs produced light, continuous forces within the 75-100 g range over a long range of activation. In contrast, the stainless steel coil springs delivered heavy forces that rapidly decayed over small activations.

The present findings indicate that the nickel-titanium coil springs would deliver a relatively constant force over a range of 7 mm tooth movement with one activation. In contrast, the stainless steel springs would deliver a very high, rapidly decaying force over a short range of tooth movement, thus requiring many activations for an equivalent tooth movement to that of the NiTi coil springs. This indicates that NiTi coil springs appear to be a superior choice to consistently deliver light, continuous forces while moving teeth. They also are the most practical because they can be used throughout the arch and require few activations, possibly only one, to produce the desired tooth movement.

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