The advantages of intra-oral, inter-arch Class II correction devices have prompted a number of new entries in that market. These active, compression devices are more acceptable to patients than external headgear, and require no patient cooperation to achieve treatment results. Since they operate in a pushing mode, these correctors unload when the patient’s jaw opens. This mode is in contrast with Class II elastics or extension springs, which load in tension upon jaw opening, producing extrusive forces at their terminal ends. The resultant forces of the compression devices are intrusive rather than extrusive, and the force vectors on the upper molars are favorable to anchorage.

When 3M Unitek began to analyze in earnest, and later develop, such devices, two major problems also became evident.

1) Enough travel must be provided in the device, or freedom in its attachment, to allow full jaw opening.

2) Loading and unloading cycles from jaw movement over time caused fatigue failure in these devices before treatment goals were achieved. A device was desired that could withstand a million cycles. This was based on an estimated 300,000 to 500,000 cycles during class II treatment, with a safety factor of 2 applied.

Among the parallel development efforts at 3M Unitek was an active spring Class II corrector designed to provide the desired advantages and eliminate the two major problems of limited travel and fatigue. A compression spring was combined with a three part telescoping assembly to provide adequate opening travel. As the spring unloads, it extends the telescoping tube assembly, allowing easy interchange of the innermost third element (the push rod) for sizing variation. The issue of fatigue fracture was addressed in the spring design.

By definition, fatigue failure is a fracture caused by repeated application of stress that is less than the breaking stress (ultimate strength) of the material. Although the working stress is less than the breaking stress, cracks initiate along the outer surface and grow with increasing cycles. When the remaining material can no longer support the localized load, the wire fractures. To obtain long fatigue life in a dynamic spring application, the spring’s working stress must be kept low. For engineering alloys used in springs, guidelines for working stresses for different service lifetimes are available in handbooks [Machinery’s Handbook, 21st Ed., 1980, Industrial Press, Inc., New York, NY 10016, pp. 494–512].

Compression spring design is a mature science. The factors that determine spring stress are the applied load, the diameter of the coil, and most importantly the wire diameter. Along with the number of coils and wire material properties, these factors define the spring. All factors are related by design formulas found in engineering handbooks [ibid]. Based on analysis of devices for similar orthodontic applications, 8 ounces-force (227 grams-force or 2.22 Newton) was selected as the approximate target maximum activation load.

The spring parameters noted above all interact and affect the overall device design. Optimizing these parameters requires iterations of spring calculation, and a computer program was used to facilitate the task. With the resulting spring design, the total working stress at the target load, corrected for curvature, is just under 63,000 psi (434 MPa), and less than 70,000 psi (483 MPa) at the maximum deflection allowed by the telescoping tubes.
The graph in Figure 1 relates stress to expected spring life for given wire sizes of the stainless steel material noted. Springs with working stress below the “Severe Service” line are expected to last one million deflections or more [ibid], with lower stress giving longer cycle life. The working stress for the 3M Unitek device is significantly lower than the allowable stress for the “Severe Service,” indicating that the spring can withstand well over 1 million cycles. For comparison, the calculated range of stress for the most similar competitive telescoping device falls well above the “Severe Service” line to just below the “Average Service” (100,000 cycles [ibid]) line.

The described spring is more than fatigue resistant in theory alone. Extensive clinical and laboratory testing of the complete device have shown cycle life in practice meets expectations. When tested in axial compression to deflections consistent with the respective manufacturers’ instructions, the 3M Unitek spring assemblies reached five million cycles without spring fracture while the similar competitive device’s springs fractured at an average less than 200,000 cycles (testing conducted at 3M Unitek from 1999 through the end of 2000).

Figure 2 shows springs removed from the competitor’s telescoping device and from the 3M Unitek device after cycle testing. The competitor’s smaller spring suffered multiple fatigue fractures on an average of less than 200,000 cycles; the 3M Unitek spring showed no fatigue fractures at 5 million cycles. While the competitive device’s spring exerts a force comparable to that of the 3M Unitek spring, its smaller size and design result in high working stresses, and as seen in Figure 2, a tendency to fail by fatigue fracture.

The factors chosen to achieve the low spring stresses also provide benefits beyond long cycle life. Although the large coil diameter places the spring on the outside of the tubes, the many coils and close pitch minimize the possibility of pinching soft tissue. Since anything not completely sealed will be in contact with saliva and food particles, the outside spring allows debris to rinse away, promoting better hygiene. The resulting low spring rate (approximately 20 gram-f/mm) provides 11 mm of active travel, as compared to a maximum 4 mm activation for flexing spring devices.

In the daily working world of product development, talking about the “Three Part Telescoping Coaxial Long Life Spring Class II Correction Device” was much too cumbersome. Since the key feature was the fatigue resistance, it was named the Fatigue Resistant Device.