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Interlot variations of transition temperature range and force delivery in copper-nickel-titanium orthodontic wires

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Introduction: The manufacturing process for copper-nickel-titanium archwires is technique sensitive. The primary aim of this investigation was to examine the interlot consistency of the mechanical properties of copper-nickel-titanium wires from 2 manufacturers. **Methods:** Wires of 2 sizes (0.016 and 0.016 × 0.022 in) and 3 advertised austenite finish temperatures (27°C, 35°C, and 40°C) from 2 manufacturers were tested for transition temperature ranges and force delivery using differential scanning calorimetry and the 3-point bend test, respectively. Variations of these properties were analyzed for statistical significance by calculating the F statistic for equality of variances for transition temperature and force delivery in each group of wires. All statistical analyses were performed at the 0.05 level of significance. **Results:** Statistically significant interlot variations in austenite finish were found for the 0.016 in/27°C ($P = 0.041$) and 0.016 × 0.022 in/35°C ($P = 0.048$) wire categories, and in austenite start for the 0.016 × 0.022 in/35°C wire category ($P = 0.01$). In addition, significant variations in force delivery were found between the 2 manufacturers for the 0.016 in/27°C ($P = 0.002$), 0.016 in/35.0°C ($P = 0.049$), and 0.016 × 0.022 in/35°C ($P = 0.031$) wires. **Conclusions:** Orthodontic wires of the same material, dimension, and manufacturer but from different production lots do not always have similar mechanical properties. Clinicians should be aware that copper-nickel-titanium wires might not always deliver the expected force, even when they come from the same manufacturer, because of interlot variations in the performance of the material. (Am J Orthod Dentofacial Orthop 2014;146:215-26)

The introduction of copper-nickel-titanium (CuNiTi) archwires to the orthodontic specialty is relatively recent. Although small variations in the ratio of nickel to titanium can have meaningful effects on the mechanical properties of orthodontic archwires, the substitution of copper for some nickel can maintain the shape-memory properties that make nickel-titanium (NiTi) wires so popular, and make the wire more stable and less sensitive to exact proportions in the alloy.[1] The clinically relevant claimed benefits of CuNiTi over NiTi wires include more constant force generation over longer activation spans, greater resistance to permanent deformation, more stable superelasticity characteristics when cyclically loaded, better spring-back, and less hysteresis.[2] Additionally, there have been claims that the CuNiTi manufacturing process allows for more consistent transition temperatures, thus providing controlled force delivery individualized for each patient.[2]

NiTi wires can exist in 1 of 2 different physical states or phases of molecular arrangement: martensite and austenite. Martensite is the pliable, low-temperature state, and austenite is the stiffer, high-temperature state. The transformation temperature range consists of the austenite start (A_s) temperature, when the alloy first begins the transformation from martensite to austenite, and the austenite finish (A_f) temperature, when the transformation is complete and the alloy becomes uniformly austenite. It is well known that the superelastic properties and thus the clinical performance of NiTi archwires directly depend on the transition temperatures of the alloy and the alloy's potential to undergo molecular changes after mechanical (deflection) or thermal (temperature) stimuli.[3] Therefore, if the addition of copper into the NiTi alloy allows for more consistency in the transition temperature of the produced wires, that should also be directly related to better consistency in clinical performance.

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According to the International Standards Organization, an accepted method of determining transition temperatures of superelastic alloys is thermal analysis via differential scanning calorimetry (DSC).[4] In this test, a sample of metal is placed in a controlled chamber and put through a cycle of cooling and heating. As superelastic wires transform through their various phases with temperature changes, enthalpy is measured and graphed. Peaks on the resultant curves represent the temperatures at which the phase changes began and ended, thus allowing determination of the transformation temperature ranges.[5]

Wire properties are extremely sensitive to the alloy ratio; small amounts of dissolved interstitial elements act as impurities and disrupt the NiTi crystal matrix and therefore its transformation behavior. Additionally, the manufacturer-specified parameters for the amount of cold work and the duration and temperature of the heat treatment and annealing processes greatly affect the archwire's final transition temperature range and therefore its force delivery.[6] Thus, it has been established that wires of similar types from different manufacturers do not necessarily possess similar properties because these manufacturing conditions are not consistent.[3] Furthermore, it is unclear to what extent all of these manufacturing materials and conditions are tightly controlled from production lot to production lot of wires from the same manufacturer. Previous studies have investigated the mechanical and thermal properties of NiTi wires. However, the authors of these studies assumed manufacturing consistency within companies, since nearly all previous wire studies that compared manufacturers used only 1 wire sample from each manufacturer to make comparisons.[6-8] Bradley et al,[6] examining transition temperature via DSC, first conducted a pilot study and established that "excellent reproducibility was achieved between nominally identical five segment samples of the same NiTi alloy," leading the authors to conclude that 1 sample from each lot was sufficient to compare the wires from different manufacturers. Interestingly, potential differences between wires made from the same manufacturer—but in different lots—have not been explored. Therefore, the purpose of this descriptive pilot study was to test the potential variability in mechanical and thermal properties among CuNiTi wires with the same advertised characteristics (ie, dimensions, A_f) from the same company to determine whether future in-depth studies of interlot variations are warranted. To our knowledge, no peer-reviewed study detailing the consistency of the NiTi manufacturing process has been published in the orthodontic literature to date.

Transformation temperature range and force delivery are 2 clinically relevant and intimately linked properties of NiTi wires: the force delivered by a wire depends on whether a deflected wire is in the austenitic or martensitic configuration or a mixture thereof. The aim of this in-vitro investigation was to evaluate the interlot consistency in the mechanical properties of CuNiTi orthodontic archwires, by attempting to detect differences in A_s, A_f, and force delivery between different manufacturers. When this study was conducted, CuNiTi archwires were commercially available from only 2 manufacturers: Rocky Mountain Orthodontics (RMO, Denver, Colo)

Table I. Number of wire types from different lots tested via DSC to determine austenite start and finish temperatures and via 3-point bend test to determine force delivery

			Wire specimens tested, each from a different lot (n)	
Manufacturer	*Size*	*Material*	*DSC*	*Three-point bend*
Ormco	0.016 in	CuNiTi 27°C	4	4
	0.016 × 0.022 in	CuNiTi 27°C	5	5
	0.016 in	CuNiTi 35°C	9	9
	0.016 × 0.022 in	CuNiTi 35°C	4	4
	0.016 × 0.022 in	CuNiTi 40°C	2	2
RMO	0.016 in	CuNiTi 27°C	3	3
	0.016 × 0.022 in	CuNiTi 27°C	3	3
	0.016 in	CuNiTi 35°C	3	3
	0.016 × 0.022 in	CuNiTi 35°C	3	3
	0.016 × 0.022 in	CuNiTi 40°C	3	3
		Totals	39	39

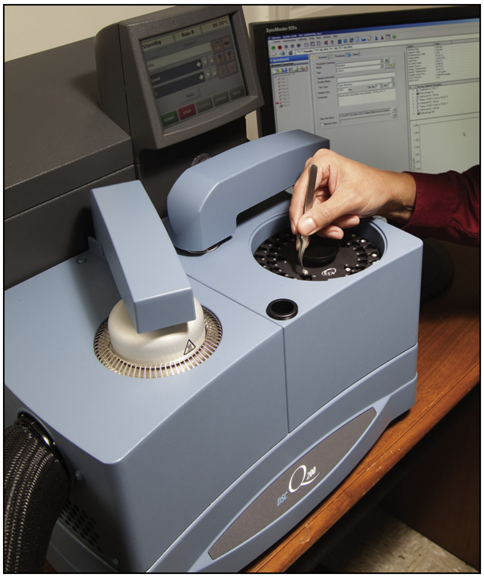

Fig 1. TA Instruments DSC machine.