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). 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.

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. 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. 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. Bradley et al, 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, A) 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, A, 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>
<thead>
<tr>
<th>Manufacturer</th>
<th>Size</th>
<th>Material</th>
<th>DSC</th>
<th>Three-point bend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ormco</td>
<td>0.016 in</td>
<td>CuNiTi 27°C</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.016 × 0.022 in</td>
<td>CuNiTi 27°C</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0.016 in</td>
<td>CuNiTi 35°C</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>0.016 × 0.022 in</td>
<td>CuNiTi 35°C</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.016 × 0.022 in</td>
<td>CuNiTi 40°C</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>RMO</td>
<td>0.016 in</td>
<td>CuNiTi 27°C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.016 × 0.022 in</td>
<td>CuNiTi 27°C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.016 in</td>
<td>CuNiTi 35°C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.016 × 0.022 in</td>
<td>CuNiTi 35°C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.016 × 0.022 in</td>
<td>CuNiTi 40°C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Totals</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig 1. TA Instruments DSC machine.
and Ormco (Glendora, Calif). Therefore, all the CuNiTi archwires tested were provided by those companies.

**MATERIAL AND METHODS**

The experimental sample consisted of CuNiTi wires of 2 dimensions (0.016 and 0.016 × 0.022 in), with variable advertised Afs (27°C, 35°C, and 40°C) and from different production lots. The wires were grouped based on the combination of dimension and Af, so each group consisted of wires with the same dimension and the same Af, but from different production lots. Production lots were determined by the information available on the package of each wire. The exact numbers of each type of archwire used in this investigation are shown in Table 1. In total, 39 wire specimens were tested; 24 were Ormco wires, and 15 were RMO wires.

The difference in numbers between the 2 companies was because no more than a few lots were readily available from RMO at the time of the study. The examiner (R.C.P.-R.) tested as many wires per lot as were easily obtainable commercially. It was considered reasonable to begin with the premise that enough precision should exist in the materials manufacturing process from one lot to another so that if even 2 lots of the same wire type from the same manufacturer showed significant differences in mechanical properties, important clinical implications could be made, or at least this would elicit the potential need for future studies. Wires from the same manufacturer and the same production lot were assumed to be identical at a molecular level, and therefore only 1 specimen from each lot was used to test the mechanical properties of the lot.

To evaluate the consistency of transition temperature ranges, each wire specimen was tested via thermal analysis with DSC (TA Instruments-Waters, New Castle, Del) as shown in Figure 1. In preparation for DSC analysis, the wires were sectioned in approximately 4-mm segments weighing approximately 3.5 mg, taken from the posterior area of each sample arch form.

Each wire segment was weighed to the nearest 0.01 mg, placed in an aluminum crucible, and sealed. An empty aluminum crucible served as the reference during the DSC measurements. The temperatures of the crucibles were scanned with nitrogen gas coolant from 60°C to −60°C and back to 60°C to protect the stability in the cell. Heating was achieved with electric heat.

Each wire specimen and reference chamber were heated and then cooled at 10°C per minute. The DSC plots were qualitatively and quantitatively analyzed by the DSC manufacturer’s software, Universal Analysis 2000 (TA Instruments-Waters). Onset and end-set temperatures of the martensitic and austenitic phases were derived from the graphs produced by the software according to standard transition temperature determination methods.

To measure the force produced by a wire as it returns to its original shape after it has been deflected, in other words, the force experienced by teeth as they are moved by a wire, a 3-point bending test was conducted by an examiner (R.C.P.-R.) using the Tinius Olsen HIKS testing machine (Tinius Olsen, Horsham, Pa). The test was performed in accordance with ISO 15841 standard.4 The machine has 2 stainless steel fulcrums 10 mm apart between their respective centers to serve as supporting points for the wire specimen, shown in Figure 2. The entire apparatus was housed in a closed chamber maintained at 37°C to simulate average oral temperature.7

All wires were sectioned into 20-mm-long specimens, rested across the 2 supporting points, and left in the temperature-stabilized testing chamber for 3 minutes, allowing the wire to reach the chamber temperature. Then each specimen was deflected from 0 to 3.1 mm and back to 0 mm with a stainless steel pointed bar measuring 0.1 mm at its head, traveling at a speed of 10.0 mm per minute. A computer attached to the testing machine recorded 1000 data points for the force placed
on and delivered by the wire through the entire loading and unloading process. Rectangular wires were measured under vertical loads that were applied on their long sides, mimicking the forces that teeth would experience when being leveled occlusogingivally. To eliminate variability from cyclic loading, measurements were taken only on specimens that had never been tested or deflected before. To compare forces upon unloading, values recorded at 2 mm of deflection were used for all statistical analyses.

### STATISTICAL ANALYSIS

To determine the statistical significance of the inter-lot variances between manufacturers in $A_s$ and $A_f$ temperatures for each type of wire sampled, the F test of equality of variances was conducted using the statistical analysis.
software R (version 2.11.1; R Development Core Team, GNU Corporation, Auckland, New Zealand). The F test was also used to compare the variances of the force exerted by each wire on unloading, at 2 mm of deflection during the 3-point bend test.

One-sample *t* tests were performed to compare the mean $A_t$ temperatures to those reported by the manufacturer. All statistical analyses were performed at the $P \leq 0.05$ level of significance.

**RESULTS**

The average $A_s$ and $A_t$ temperatures for each type of wire tested, along with descriptive statistics detailing the spread of data in each group, are summarized in Table II. Also, the graphs produced by the DSC testing machine are presented in Figures 3 and 4.

DSC testing of 0.016-in archwires with an advertised $A_t$ of 27°C showed a statistically significant difference in
interlot variation in $A_f$ between the 2 manufacturers ($P = 0.041$). The average $A_f$ for the RMO 0.016 in/ 27°C archwires was 28.52°C (SD, 0.39°C); for the Ormco wires, the average $A_f$ was 24.98°C (SD, 2.69°C). No significant differences were detected regarding $A_s$ ($P = 0.14$).

DSC testing of the 0.016-in archwires with an advertised $A_f$ of 35°C showed no significant differences between the 2 manufacturers in interlot variations of $A_f$ ($P = 0.432$) or $A_s$ ($P = 0.194$).

In DSC testing of the 0.016 × 0.022-in archwires with an advertised $A_f$ of 27°C, similarly, the 2 manufacturers did not differ significantly in interlot variations of $A_f$ or $A_s$ for these archwires ($A_f$, $P = 0.443$; $A_s$, $P = 0.211$).

DSC testing of the 0.016 × 0.022-in archwires with an advertised $A_f$ of 35°C showed a statistically significant difference in interlot variations of both $A_f$ ($P = 0.048$) and $A_s$ ($P = 0.010$). It appeared that the variations in $A_f$ and $A_s$ were much greater in wires of this type made by Ormco, as clearly shown by the significantly higher standard deviations (Table II).

The DSC testing of the 0.016 × 0.022-in archwires with an advertised $A_f$ of 40°C showed no significant difference in interlot variations of $A_f$ and $A_s$ between the 2 manufacturers ($A_f$, $P = 0.540$; $A_s$, $P = 0.319$).

When the mean $A_f$ values of the archwires from both manufacturers were compared with the advertised $A_f$ values, no significant differences were apparent ($0.627 \geq P \geq 0.063$), although most values were lower than the advertised ones.

Furthermore, it appeared that for wires with a dimension of 0.016 × 0.022 in and an advertised $A_f$ of 40°C, the actual $A_f$ values measured with the DSC test were not only lower than 40°C but even lower than 35°C; this places them in a totally different category of archwires (Table II).

The results of the 3-point bend test showed statistically significant differences between manufacturers in interlot force delivery variations on unloading, after 2 mm of wire deflection (Table III). In both types of 0.016-in archwires, Ormco wires appeared to have significantly greater interlot variations in force delivery (27°C, $P = 0.02$; 35°C, $P = 0.049$). Similarly, when


**Table III. Unloading force exerted by wires at 2 mm of unloading**

<table>
<thead>
<tr>
<th>Wire (no. of specimens tested)</th>
<th>Average load at 2 mm (g)</th>
<th>Load at 2 mm, range</th>
<th>Load at 2 mm, SD</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMO 0.016 in/27°C (3)</td>
<td>94.38</td>
<td>2.27</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>Ormco 0.016 in/27°C (4)</td>
<td>112.91</td>
<td>87.62</td>
<td>40.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td>RMO 0.016 in/35°C (3)</td>
<td>87.16</td>
<td>6.87</td>
<td>4.52</td>
<td></td>
</tr>
<tr>
<td>Ormco 0.016 in/35°C (9)</td>
<td>95.44</td>
<td>87.17</td>
<td>28.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.049</td>
</tr>
<tr>
<td>RMO 0.016 × 0.022 in/27°C (3)</td>
<td>191.35</td>
<td>13.73</td>
<td>7.30</td>
<td></td>
</tr>
<tr>
<td>Ormco 0.016 × 0.022 in/27°C (5)</td>
<td>283.18</td>
<td>117.30</td>
<td>42.15</td>
<td>0.057</td>
</tr>
<tr>
<td>RMO 0.016 × 0.022 in/35°C (3)</td>
<td>160.50</td>
<td>13.23</td>
<td>7.07</td>
<td></td>
</tr>
<tr>
<td>Ormco 0.016 × 0.022 in/35°C (4)</td>
<td>214.18</td>
<td>131.81</td>
<td>56.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.031</td>
</tr>
<tr>
<td>RMO 0.016 × 0.022 in/40°C (3)</td>
<td>106.99</td>
<td>19.42</td>
<td>10.04</td>
<td></td>
</tr>
<tr>
<td>Ormco 0.016 × 0.022 in/40°C (2)</td>
<td>95.65</td>
<td>44.95</td>
<td>31.78</td>
<td></td>
</tr>
</tbody>
</table>

*P < 0.05; P < 0.010.

0.016 × 0.022-in archwires with an advertised $A_f$ of 35°C were tested. Ormco wires also had significantly greater interlot variations in force delivery ($P = 0.031$). However, other types of 0.016 × 0.022-in archwires did not appear to be statistically different between manufacturers in interlot force delivery variation (27°C, $P = 0.057$; 40°C, $P = 0.174$).

**DISCUSSION**

One unique aspect of CuNiTi wires that has been touted in some of its marketing is that each wire has been engineered to have a specific $A_f$ temperature, implying a significant correlation between a tightly controlled $A_f$ and a specific force delivery. This allows the clinician to choose a CuNiTi wire of 1 dimension but with 3 varying degrees of force: the 27°C wire would be austenitic at both room temperature (average, 22°C) and at most oral temperatures (average, 36°C) for maximum force delivery. The 35°C wire should be martensitic at room temperature but partially to totally austenitic at oral temperatures. The 40°C wire is expected to be martensitic at both room and average oral temperatures, theoretically allowing for the lightest delivery of forces. The validity of these claims depends on the accuracy and precision of the transition temperature range for each wire; in this study, we attempted to confirm this while also correlating the experimental transition temperatures to the force delivery, which is ultimately the property of concern to clinicians.

The novelty of this study lies in its questioning of the easy assumption that all wires of a similar type from the same manufacturer have similar clinical behavior. However, our results demonstrate that this is not necessarily the case. Data from the 2 manufacturers show different degrees of variations in forces among production lots. When interlot force variations are large, the doctor cannot be assured of the same clinical outcomes among patients.

Previous investigations have also tested the accuracy of transition temperature values reported by wire manufacturing companies. Kusy and Whitley used DSC testing to evaluate the mechanical properties of different types of archwires and found that actual $A_f$ values are mostly a few degrees different from those reported by the manufacturers. Thus, they concluded that companies tend to be relatively accurate in reporting the $A_f$ values of their archwires. Similarly, Biermann et al examined the transition temperatures of Ormco CuNiTi wires via DSC and found that for wires advertised to have $A_s$ of 27°C and 35°C, the experimental $A_f$ was within 2°C of the claimed $A_f$ for every wire tested. For the wires advertised to have an $A_f$ of 40°C, the experimentally determined $A_f$ was on average 4°C less at 36°C. This finding agrees with our results, which also showed a significant difference between the actual and reported $A_f$ values of CuNiTi archwires that are advertised to have an $A_f$ of 40°C.

Biermann et al speculated that this 4°C difference could be related to an inherent variation between production lots of wire made by the same manufacturer. Our study confirmed that interlot variations in transition temperatures and force delivery are not uncommon in CuNiTi archwires. As a result, commercially available archwires do not necessarily perform as expected. This is particularly true for wires with a higher advertised $A_f$.

If there is variation among the transition temperatures of wires made by the same manufacturer because of the technique-sensitive nature of the manufacturing process, it stands to reason that a NiTi wire and its variants made by different manufacturers would also exhibit differences in mechanical properties. This question was examined by Nakano et al, who conducted 3-point bend tests on 42 categories of NiTi wires, including CuNiTi, made by 9 manufacturers. Their results showed that NiTi wires (including thermal CuNiTi and superelastic NiTi) of different brands but of the same diameter varied in unloading force at 1.5 mm of deflection by as much as 337 g. For orthodontic purposes, forces much lighter than this, in the range of 35 to 100 g, are...
considered optimal for tipping, rotating, extruding, and root uprighting, the actions most often intended to be the result of initial leveling and aligning with NiTi wires.\textsuperscript{11}

If the force a superelastic orthodontic wire exerts on a tooth is largely dependent on the temperature at which it begins to transform from martensite to austenite (As) and the temperature at which that transformation is completed (Af), then the force delivered on unloading at 2 mm of deflection can be analyzed. This table shows evidence that there may be a correlation between low As and Af and higher forces; and conversely, a correlation between high As and Af and lower forces.

*Denotes the lowest value in the column category among the lots of the same wire type and manufacturer tested; \textsuperscript{y}denotes the highest value in the column category among the lots of the same wire type and manufacturer tested.

This table shows evidence that there may be a correlation between low As and Af and higher forces; and conversely, a correlation between high As and Af and lower forces.
Fig 5. Interlot load vs deflection curves for each type of wire tested, overlayed.
transformation is complete ($A_f$), it follows that precise engineering of each wire's transition temperature range—both $A_s$ and $A_f$—is key for the wire to behave clinically as expected. The data in Table IV agree with this because they demonstrate a possible relationship between both $A_s$ and $A_f$—not just $A_f$ as advertised—and force delivery. Visual observations of these data suggest a potential inverse relationship between $A_s$, $A_f$, and force delivery.

Several factors influence the final transition temperatures of a wire: the initial proportion of metals in the alloy ingot, the annealing conditions, the amount of cold work done, and the amount of time and temperature at which the wire is heat treated. Small variations in these factors can yield huge effects on phase transformation temperatures. If the manufacturing process is indeed as sensitive as indicated, then the question is raised as to whether an orthodontist can reasonably expect manufacturers to be consistent in the force delivery properties of their archwires.

The results of this study demonstrate notable differences among production lots of the same wire type from the same manufacturer. In addition, significant differences were found between manufacturers in certain wire types. It appeared that certain archwires made by Ormco had greater interlot variabilities in transition temperature and force delivery values. This was true for 0.016-in ($A_f, 27^\circ C$), 0.016-in ($A_f, 35^\circ C$), and 0.016 × 0.022-in ($A_f, 35^\circ C$) archwires. A cursory visual inspection of the DSC graphs (Fig 4) and the load vs deflection graphs (Fig 5) also highlights the differences among the same wire types from various lots from the 2 manufacturers. On the DSC graphs, the slopes of enthalpy and peak heights for each wire of the same type and maker but from different lots are notably not parallel for the Ormco wires. This indicates

![Graphs of wire data](image-url)
variations in martensite start, martensite finish, $A_m$ and $A_f$ from lot to lot. Regarding RMO wires, the slopes of enthalpy and peak heights from the DSC tests demonstrated that most wires in every category had near parallel slopes of similar heights, indicating greater consistency in the transition temperature ranges for each wire in every lot. Similar observations can be made when looking at the overlaid graphs of load vs deflection.

A possible explanation for the differences between the 2 manufacturers is related to the length of time each company has had its product commercially available. Since Ormco CuNiTi wires have been available on the market for several years, it is possible that Ormco has been changing its parameters for these wires over time, and this might account for the changes seen in transition temperatures and force delivery. Since the dates of wire manufacturing were not available on the wire packages, it is possible that the wires we tested were made several years ago, when Ormco might have had a different manufacturing protocol. RMO has just recently released its CuNiTi wire and presumably determined one formulation that has stayed consistent on the few batches of wires released to date.

Another possible reasoning behind these differences could be associated with how different factors are being considered by companies during the manufacturing process. For example, it appears that not only $A_f$ but also $A_m$ could impact the overall performance of a wire and affect force delivery values.

There are several limitations of this study. Because of the availability of wires at the time of data collection, the sample sizes for each type of wire were small and not equal for RMO and Ormco. In addition, there was no method of randomization in the selection of wires to be tested, so it is not clear whether the wire samples were equally representative of all the lots produced by each company. Nevertheless, it was considered reasonable to assume that a manufacturing process should be precise enough to have low tolerances in material properties from one production lot to another. Although a small sample size might have reduced the ability to determine the statistical significance in the variations, it is clinically significant that the ranges of force delivery from lot to lot were as high as $131.8$ g of force for what should have been the same wire. Since only one sample from every lot was tested there is the possibility of intralot variation, which could not be detected but is reasonably expected to be significantly less than interlot variation. Therefore, our results must be reinforced by future studies including larger samples of wires. However, it is important to identify significant variations of mechanical and thermal properties in the same manufacturer. Due to these variations, results from previous studies should be viewed critically because they are based on measurements of one wire from each manufacturer, assuming excellent quality control by the companies.

It should also be considered that the 3-point bend test is an in-vitro test that poorly mirrors in-vivo conditions. Clinically, when a wire is engaged in the brackets, the incisogingival and buccolingual displacements of every tooth as well as the mesiodistal distances between brackets all affect the amount of force delivered by a wire to a tooth. Additionally, as the wire undergoes cyclic loading with masticatory function and temperature variations throughout the day in the moist oral environment, force delivery is again affected. Therefore, it is important to remember that the numbers given here and in similar studies for force delivery are valid only in that they allow comparison of one wire’s behavior relative to another’s in one isolated environment under similar conditions and do not actually reflect the forces experienced by teeth in a given clinical situation.

CONCLUSIONS

Wires of the same materials, dimensions, and manufacturer but from different production lots do not always have similar mechanical properties. Differences in interlot variations exist between manufacturers of CuNiTi archwires. Improvements should be made in the manufacturing process of archwires to provide clinicians with CuNiTi archwires that have consistent mechanical properties.

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REFERENCES