Alleviation of mandibular anterior crowding with copper-nickel-titanium vs nickel-titanium wires: A double-blind randomized control trial

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Introduction: The purpose of this study was to investigate the efficiency of copper-nickel-titanium (CuNiTi) vs nickel-titanium (NiTi) archwires in resolving crowding of the anterior mandibular dentition. **Methods:** Sixty patients were included in this single-center, single-operator, double-blind randomized trial. All patients were bonded with the In Ovation-R self-ligating bracket (GAC, Central Islip, NY) with a 0.022-in slot, and the amount of crowding of the mandibular anterior dentition was assessed by using the irregularity index. The patients were randomly allocated into 2 groups of 30 patients, each receiving a 0.016-in CuNiTi 35°C (Ormco, Glendora, Calif) or a 0.016-in NiTi (ModernArch, Wyomissing, Pa) wire. The type of wire selected for each patient was not disclosed to the provider or the patient. The date that each patient received a wire was recorded, and all patients were followed monthly for a maximum of 6 months. Demographic and clinical characteristics between the 2 wire groups were compared with the *t* test or the chi-square test and the Fisher exact test. Time to resolve crowding was explored with statistical methods for survival analysis, and alignment rate ratios for wire type and crowding level were calculated with Cox proportional hazards multivariate modeling. **Results:** The type of wire (CuNiTi vs NiTi) had no significant effect on crowding alleviation (129.4 vs 121.4 days; hazard ratio, 1.3; $P > 0.05$). Severe crowding (>5 on the irregularity index) showed a significantly higher probability of crowding alleviation duration relative to dental arches with a score of <5 (138.5 vs 113.1 days; hazard ratio, 2.2; $P = 0.02$). **Conclusions:** The difference of the loading pattern of wires in laboratory and clinical conditions might effectively eliminate the laboratory-derived advantage of CuNiTi wires. (Am J Orthod Dentofacial Orthop 2009;136:152.e1-152.e7)

Nickel-titanium (NiTi) archwires have had wide acceptance in the orthodontics because their low load-deflection ratio, which provides a desirable force level and better control of force magnitude.[1-3] NiTi wires were initially classified as superelastic, nonsuperelastic, and true shape memory. However, this classification was confusing, and, as a result, an alternative, structure-based classification was proposed: (1) martensitic stabilized, which show a stable martensitic structure and thus no shape memory or superelasticity is expressed; (2) martensitic active, also termed thermoactive, in which an increase in temperature leads to transformation of the martensitic back to the austenitic structure; and (3) austenitic active, with pseudoelastic behavior, when the martensitic structure transformation of these alloys is stress-induced, resulting from activation of the wire.[4]

Most studies of the mechanical properties and structural conformation of NiTi wires used 3 major routes to elucidate certain aspects of wire structure and performance. The most commonly used method consists of deflection curves, or cantilever testing of segments of archwires under various loading patterns. A problem with this method might be that superelasticity is, by definition, a property referring to the crystallographic structural elements of the material, and, depending on the mechanical test, the response of the wires to loading can differ. On the other hand, x-ray diffraction studies of archwires are limited by the inherently near-surface nature of this technique, which has a 50-μm penetration depth, thus providing evidence for the surface layers of the material.[5] Alternatively, differential scanning calorimetry, which in principle determines the enthalpy for structural transformations, can provide information about the bulk material.[6]

Apart from limitations on the analytic tools used in relevant research, there is some skepticism because the actual clinical performance of these wires in the intraoral

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environment has not been studied to the same extent as their mechanical properties. Studies assessing the rate of tooth movement during treatment with different archwire alloys showed no significant differences among superelastic, nonsuperelastic NiTi wires, and multistranded stainless steel wires.[7] Moreover, superelasticity seems to have little clinical importance for torque application, since at least 45° of activation is necessary to induce a deactivation plateau.[8] Also, many superelastic wires show no superelastic properties in vivo, or at least no advantage over nonsuperelastic NiTi wires,[9] because of the exceedingly high force level at the plateau that is not seen in clinical conditions.[10]

Likewise, there is a notable lack of evidence on the widely suggested combination of NiTi archwires and self-ligating brackets. The latter show a favorable engagement pattern with consistent engagement force, attributed to the elimination of force decay of elastomeric ligatures; this might be as much as 50% of the initial force.[11] Therefore, these brackets have been proposed to take full advantage of the properties of NiTi archwires.

The null hypothesis of this study was that there is no difference in the time to resolve crowding with the 2 NiTi wires used. The purpose of this study was to investigate the clinical efficiency of copper-NiTi (CuNiTi) vs NiTi archwires in resolving mandibular anterior crowding.

MATERIAL AND METHODS

Sixty patients, 10 to 18 years of age (mean, 13.1 years), were included from the private orthodontic office of the first author (N.P.). This clinical trial, conducted between December 2006 and March 2008, was a single-center, single-operator, double-blind investigation. Selection of participants from a large pool of patients was based on the following inclusion criteria: nonextraction treatment on the mandible, eruption of all mandibular teeth, no spaces in the mandibular arch, no crowding in the posterior segments, mandibular irregularity index greater than 2, and no therapeutic intervention planned involving intermaxillary or other intraoral or extraoral appliances including intra-arch or interarch elastics, lip bumpers, maxillary expansion appliances, or headgears.

All patients were bonded with the In Ovation-R self-ligating bracket with a 0.022-in slot (GAC, Central Islip, NY). All first and second molars (when present), were bonded with bondable tubes (Speed System Orthodontics, Cambridge, Ontario, Canada). Bracket bonding, archwire placement, and treatment were performed by the same clinician.

The amount of crowding of the mandibular anterior dentition was assessed with the irregularity index described by Little.[12] Measurements were made intraorally twice by the same clinician using a fine-tip digital caliber (Digimatic NTD12-6-in C, Mitutoyo, Kanagawa, Japan), and the means of the 2 measurements were entered into an Excel spreadsheet (Microsoft, Redmond, Wash). Randomization was done using random permuted blocks of size 6. Opaque envelopes were used to allocate treatment. One group received a 0.016-in CuNiTi 35°C wire (Ormco, Glendora, Calif); the other group received a 0.016-in NiTi wire (ModernArch, Wyomissing, Pa). Allocation of wires was concealed from the investigator and the participants during the observation period, and no other wire was used throughout the study.

The date that each patient received a wire was recorded, and all patients were followed monthly for a maximum of 6 months. Assessment of the alleviation of crowding involved only the mandibular anterior teeth; in other words, a patient was considered to have reached alignment if the 6 mandibular anterior teeth were aligned, regardless of remaining irregularities in the buccal segments.

The primary outcome measure was time to alignment of the mandibular anterior dentition, determined as the time from first archwire placement to complete alignment, according to the operator. The observation period ended after 6 months of intervention for all patients; for patients not aligned after 6 months of active treatment, the remaining crowding was recorded. In this case, the irregularity index was measured intraorally, and the mean of the 2 measurements was recorded.

The planned sample of 60 subjects was based on a time-to-event analysis, with a power of 80% to detect a 45% difference in effect (hazard ratio) and for type I error of 0.05.[13] Demographic and clinical characteristics were investigated with conventional descriptive statistics. Comparisons between the 2 wire groups were conducted with the t test or chi-square test and the Fisher exact test, depending on the examined variable (numerical or categorical) at the 0.05 level of significance. Time to resolve crowding was explored with statistical methods for survival analysis, and alignment rate ratios for wire type and crowding level were calculated with Cox proportional hazards regression modeling. This multivariate model allowed the calculation of alignment rate ratios with adjustment for covariants such as age, sex, and Angle classification. All analyses were done with the STATA statistical package (version 10.0, StataCorp, Houston, Tex).

RESULTS

Figure 1 presents the CONSORT flowchart for participation. From 85 patients assessed for eligibility, 60 met the eligibility criteria, were included in the study, and were randomized and analyzed.

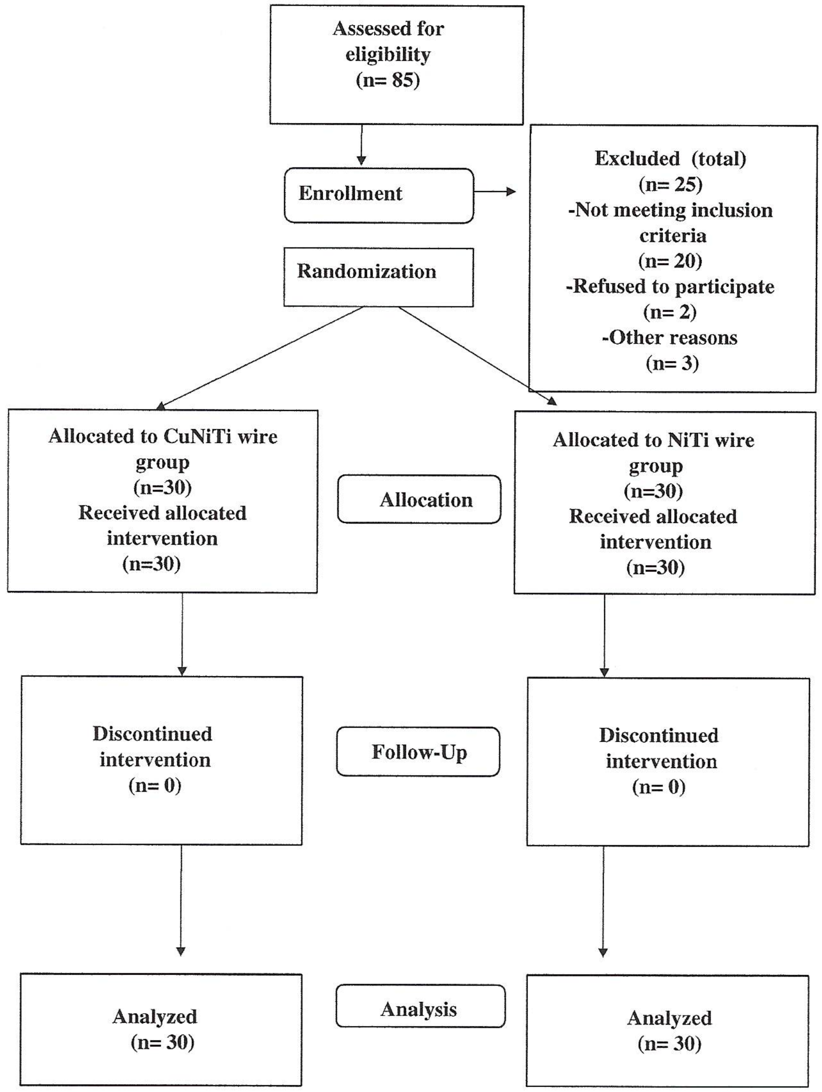

Fig 1. CONSORT flowchart diagram of the clinical trial.

Table I shows the variability of the sample by clinical and demographic characteristics; no variable was identified to discriminate the 2 samples, thus verifying the random allocation of the intervention to the 2 wire groups.

In Table II, data for the duration of treatment to resolve crowding by wire and crowding are given. The type of wire (CuNiTi or NiTi) had no significant effect on crowding alleviation (121.4 vs 129.4 days; $P>0.05$). Severe crowding (>5 on the irregularity index), on the other hand, had a significantly higher probability of crowding alleviation duration relative to the dental arches with an index score of <5 (138.5 vs 113.1 days; $P=0.02$). In 50% of the patients with moderate crowding, alignment was achieved within 3.5 months; in 50% of the patients with severe crowding, alignment required 5 months.

Figure 2 depicts the variations of treatment duration related to wire (Fig 2, *A*) and severity of crowding (Fig 2, *B*). Although wire type did not result in consistent separation of the 2 curves, the persistence of the alignment completion pattern during the treatment period indicated that patients with severe crowding were more likely to have incomplete alignment compared with patients with moderate crowding at any treatment time.

Table III shows adjusted hazard ratios for age, sex, and Angle classification, used to describe the outcome of this trial, when the question was to what extent type of wire and degree of crowding might affect the probability of alignment (outcome). This study suggests

Table I. Demographics and clinical characteristics of sample

	Total (n = 60) Mean or %	*SD*	*CuNiTi (n = 30) Mean or %*	*SD*	*NiTi (n = 30) Mean or %*	*SD*	P *value**
Demographic characteristic							
Age (y)	13.1	1.8	13.4	1.8	12.8	1.7	NS
Sex (%)							
Female	76.7		70.0		83.4		NS
Male	23.3		30.0		16.6		
Clinical characteristics							
Crowding (irregularity index)	5.5	2.1	5.3	2.3	5.6	2.0	NS
Crowding (%)							
Severe	48.4		43.4		53.4		NS
Moderate	51.6		56.6		46.6		
Angle Class (%)							
I	53.4		56.7		50.0		NS
II	45.0		43.3		46.7		
III	1.6		0.0		3.3		

NS, Not significant.
**P* value for comparison of group means by *t* test or differences in proportions by chi-square test and Fisher exact test.

Table II. Treatment time to alignment characteristics by wire system and crowding severity

	Total	*Successfully aligned*	*Mean time to alignment (days)*	*Minimum (days)*	*Median (days)*	*Maximum (days)*	P *value**
Wire type							
CuNiTi	30	19	129.4	32	142.5	195.0	
NiTi	30	22	121.4	28	116.5	190.0	NS
Crowding							
Severe (index >5mm)	29	16	138.5	32	152.0	190.0	
Moderate (index ≤5mm)	31	25	113.1	28	104.0	195.0	<0.05

NS, Not significant.
**P* value based on log-rank test for equality of survivor functions.

statistical insignificance with a hazard ratio of 1.3 for the NiTi group, whereas moderate crowding showed statistical significance with a hazard ratio of 2.2. Because of several misconceptions about the use of this notation, it should be noted that a hazard ratio of 2 does not imply that the treatment duration of moderate crowding is half of that for the subjects with severe crowding; rather, it suggests that a patient in the moderate crowding group has more than double the chance to complete alignment compared with a person in the severe crowding group.[14] Hazards ratios in Table III should be evaluated with Table II, where the actual difference to complete alignment between the groups is shown in days.

DISCUSSION

The null hypothesis could not be rejected, and thus no difference in alignment was noted between CuNiTi thermoactive archwires and NiTi wires. On the contrary, increased irregularity was found to be associated with longer treatment periods. The latter might be due to alterations of transformation temperature ranges in vivo, limiting the transformation of NiTi archwires, or to the overall irrelevance of laboratory-derived mechanical behavior of wires to the loading conditions of clinical situations.

The first hypothesis used the effect of oral cavity conditions as a key variable affecting the clinical performance of the wires. Intraoral aging is known to cause significant morphologic and structural alterations, including destruction of the structural integrity of NiTi wires, delamination, formation of craters, and increased porosity. In addition, the surface profile of retrieved wires showed vast changes with precipitation of calcium and phosphorus complexes from the calcification of adsorbed integument.[15]

Although many studies have highlighted the alterations of wires in vivo, the sole evidence on the effect

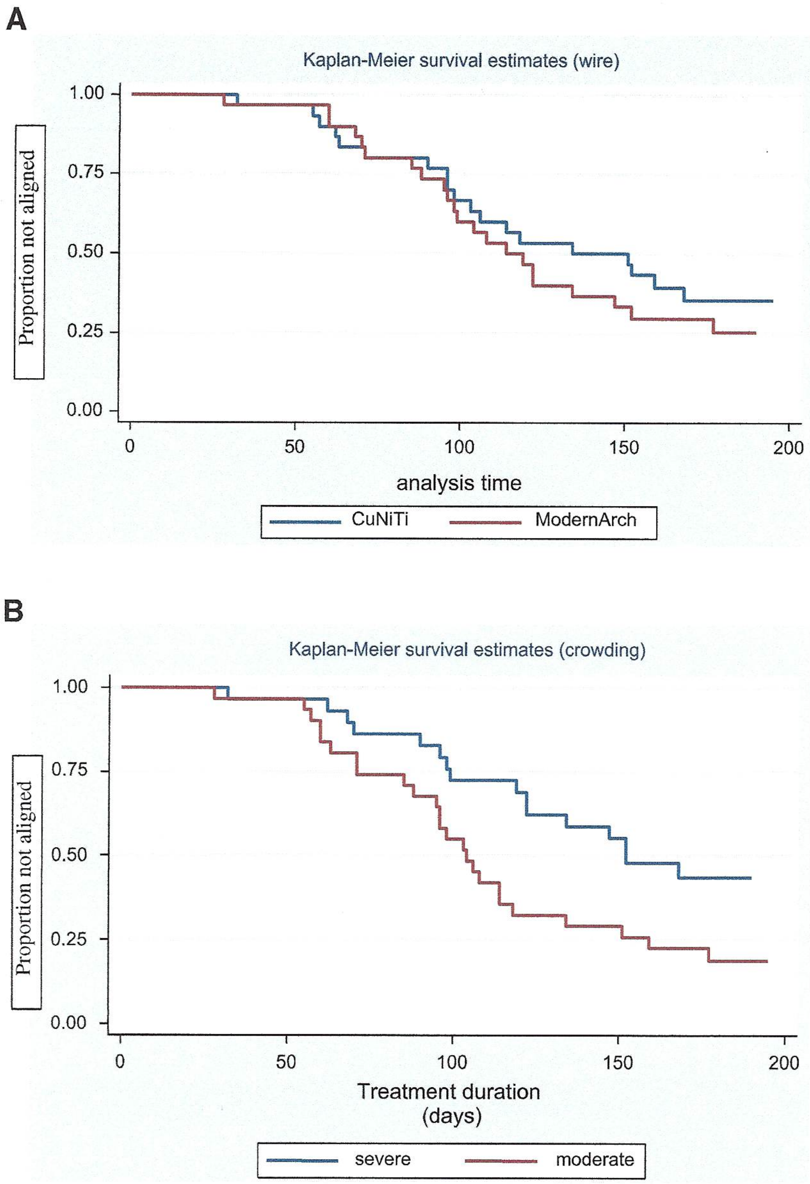

Fig 2. Variations of treatment duration as it relates to **A,** wire and **B,** severity of crowding. The y-axis provides the proportion of patients still in treatment (not aligned) at different time variants (days on x-axis). By drawing a line perpendicular to the x-axis at a given time value, the proportions of patients not completed for each wire (*A*) and crowding (*B*) group are extrapolated from the corresponding value of the y-axis. Note the lack of separation of wire groups implying a lack of effect, as opposed to the persistence of the alignment completion pattern throughout treatment: severe crowding had a higher percentage of incomplete cases compared with moderate crowding at any time.

of intraoral conditions on the transformation of CuNiTi wires comes from a recent article that assessed the differential scanning calorimetry parameters of intraorally exposed and as-received wires.[16] This investigation reported no difference between as-received and clinically retrieved wires in key variables related to phase transformation, except for a significant reduction in heating enthalpy associated with the martensite-to-austenite transition in the 27°C CuNiTi archwires. Therefore, the lack of difference between NiTi and CuNiTi specimens cannot be assigned to the intraorally induced phase transformation variables of the latter.

However, the temperature sensitivity of superelastic NiTi wires indicates that variations in mouth temperature

Table III. Alignment rate ratios derived from Cox proportional hazards regression

Predictor	*Adjusted hazard ratio*†	*95% confidence interval*	*P value*
Wire type			
CuNiTi	Baseline		
NiTi	1.3	0.7-2.5	NS*
Crowding			
Severe (index >5mm)	Baseline		
Moderate (index <5mm)	2.2	1.6-4.0	0.02

**NS,* Not significant; †Hazard ratios adjusted for demographic characteristics and Angle Class.

could cause stress fluctuations in NiTi wires during orthodontic treatment.[17] An interesting protocol involved examination of the response of NiTi wires at a constant temperature and at stepwise temperature changes from 37°C to 60°C and back to 37°C, and from 37°C to 2°C and back to 37°C, to evaluate the effects of temperature changes on the mechanical properties of the wires.[17] It was found that the load expressed by the superelastic NiTi wires increases on heating and decreases on cooling. These phenomena were associated with a change in the critical stress for martensite transformation induced by temperature changes. Interestingly, in the stepwise temperature changes on heating, the load measured at body temperature as the final step was much higher than that measured at 37°C as an initial step. Also, cooling the wires induced transient effects in the deactivation phase but prolonged effects when the wires were tested in the activation phase. In contrast, the effect of short-term heating showed the opposite pattern.[18]

Evidence indicating the dependence of mechanical properties of superelastic NiTi wires on temperature changes has also been presented by others using a different approach. True shape-memory wires continued to exert subbaseline bending force after short-term application of cold water, and this effect remained even after 30minutes of postexposure restitution.[19] In addition, annulling this effect required a temperature increase to about 50°C by intake of a hot drink.[20]

The previous discussion suggests that, despite the lack of significant phase transformational changes of used superelastic NiTi wires, the temperature dependence of thermoactive wires might differentiate their behaviour in vivo.

An alternative hypothesis pertains to the differences of loading conditions between laboratory conditions and the oral cavity. In general, loading the NiTi archwire from its engagement in the bracket slot walls gives a much different pattern than free NiTi wire segments subjected to 3-point, or cantilever, bending. The unique character of loading during engagement is due to the free play or slack between the archwire and the slot.[21] This pattern cannot be simulated in laboratory configurations and might differentiate the performance of the material. This effect, along with the unrealistic force variants at which plateau levels are reached in the stress-strain curve of NiTi wires, might preclude the expression of the full spectrum of properties of NiTi archwires.[10]

Support for the latter notion is provided by studies assessing the force levels of self-ligating brackets. Variations in the design of the closing mechanism of the 2 self-ligating brackets in this study might affect the force generated by the displaced bracket because direction has been shown to alter force magnitude in active self-ligating brackets. Specifically, intrusive and extrusive forces with self-ligating brackets have decreased magnitude, whereas this difference can be eliminated for lingually directed displacements.[22]

Additionally, a source of variability are the aging alterations of the clip of active self-ligating brackets during orthodontic treatment; these might modify the forces generated during wire engagement. The stiffness of the ligating mechanism in active self-ligating brackets shows stress relaxation, and the reduced force applied to the archwire might also contribute to lower forces exerted by the bracket, potentially precluding the development of necessary force magnitudes for the initiation of the superelastic plateau.[23]

CONCLUSIONS

These results suggest that thermoactive NiTi wires have no advantage over their counterparts in shortening the duration of alignment in mandibular anterior crowding.

The degree of crowding, as expected, has an effect on the length of treatment: patients with severe crowding (irregularity index >5) have a significantly longer treatment compared with moderately crowded ones (irregularity index <5).

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