Original Article

pISSN 2234-7518 • eISSN 2005-372X
https://doi.org/10.4041/kjod.2018.48.3.153

THE KOREAN JOURNAL of ORTHODONTICS

Evaluation of the alignment efficiency of nickel-titanium and copper-nickel-titanium archwires in patients undergoing orthodontic treatment over a 12-week period: A single-center, randomized controlled clinical trial

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Objective: The aim of this trial was to compare the alignment efficiency and intermaxillary arch dimension changes of nickel-titanium (NiTi) or copper-nickel-titanium (CuNiTi) round archwires with increasing diameters applied sequentially to the mandibular arch. **Methods:** The initial alignment phase of fixed orthodontic treatment with NiTi or CuNiTi round archwires was studied in a randomly allocated sample of 66 patients. The NiTi group comprised 26 women, 10 men, and the CuNiTi (27°C) group comprised 20 women, 10 men. The eligibility criteria were as follows: anterior mandibular crowding of minimum 6 mm according to Little's Irregularity Index (LII), treatment requiring no extraction of premolars, 12 to 18 years of age, permanent dentition, skeletal and dental Class I malocclusion. The main outcome measure was the alignment of the mandibular anterior dentition; the secondary outcome measure was the change in mandibular dental arch dimensions during 12 weeks. Simple randomization (allocation ratio 1:1) was used in this single-blind study. LII and mandibular arch dimensions were measured on three-dimensional digital dental models at 2-week intervals. **Results:** No statistically significant difference was observed between NiTi and CuNiTi according to LII ($p > 0.05$). Intercanine and intermolar arch perimeters increased in the CuNiTi group ($p < 0.001$). Inter-first premolar width showed a statistically significant interaction in week × diameter × application ($p < 0.05$). **Conclusions:** The effects of NiTi and CuNiTi round archwires were similar in terms of their alignment efficiency. However, the intercanine and intermolar arch perimeters, and the inter-first premolar width changes differed between groups.
[Korean J Orthod 2018;48(3):153-162]

Key words: Three-dimensional digital dental cast analysis, Nitinol, Copper-nickel-titanium, Wire

Received April 20, 2017; Revised August 29, 2017; Accepted October 7, 2017.

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The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.

INTRODUCTION

By changing the mechanical properties of a material and, hence, the content of an alloy, we could possibly obtain ideal archwire characteristics required at each stage of fixed orthodontic treatment.[1] Nickel-titanium (NiTi) wires are preferred by clinicians because compared to stainless steel wires, they have a wider working range and higher springback properties.[2] Nitinol, which is categorized in the M_{stab} group, contains 55% nickel and 45% titanium, and is also known as "M-NiTi".[3] This material has high springback values, despite having neither superelasticity nor a shape-memory effect.[4] Copper-nickel-titanium (CuNiTi) wires, which fall into the M_{act} group, have a true shape-memory effect and show the mechanical properties of austenite above a transition temperature range. CuNiTi archwires can be ligatured easily at room temperature (approximately 25°C, below the transition temperature range) in the martensitic phase (soft and flexible). After intraoral application, this wire shows mechanical properties of the austenite phase under oral conditions, i.e., its hardness increases, becomes inflexible, and shows function while taking its true shape (form).[5,6] In CuNiTi wires, the addition of copper into the alloy reduces hysteresis and helps control the transition temperature range.[7] The copper content of CuNiTi archwires also enables these wires to exert more homogeneous forces from one side of the wire to the other, thereby providing faster and more efficient tooth movement.[8,9]

Several studies have evaluated NiTi archwires with different alloy compositions and, therefore, variable mechanical characteristics *in vitro*,[9,10] clinical performance *in vivo*,[11,12] and different effects on pain levels.[13] However, the results obtained using *in vitro*[9,10] vs. *in vivo*[11,12,14] conditions are controversial. Therefore, more *in vitro* studies are needed which are designed to evaluate the efficiency of NiTi wires at the initial stage of treatment with respect to the alleviation of crowding.[15]

A wide variety of archwire sequences have been used to compare the clinical efficiency of orthodontic archwires.[16-18] Identifying an archwire sequence that reflects the clinical routine would increase the usefulness of the study results in daily orthodontic practice.[19] However, insufficient data are available to determine the archwire sequence that would alleviate crowding most rapidly and efficiently at the leveling stage of fixed orthodontic treatment.[20]

In the literature, several studies have compared the clinical efficiency of M_{stab} NiTi and M_{act} NiTi wires.[12,14,16] However, to the best of our knowledge, no *in vitro* randomized controlled study has evaluated the clinical performance of round archwires at the initial stage of orthodontic treatment when these are used sequentially with respect to the clinical routine.

The aim of this study was to evaluate the efficiency of round NiTi and CuNiTi archwires used at the initial stage of orthodontic treatment in a sequence that reflects the clinical routine. The first hypothesis of this study is, "There is no difference between round NiTi and CuNiTi archwires in terms of the alleviation of crowding in the anterior segment of the mandible at the leveling stage." The second hypothesis is, "There is no difference between round NiTi and CuNiTi archwires in terms of the evaluation of arch perimeters and interdental widths at the leveling stage."

MATERIALS AND METHODS

This study was a randomized, parallel-group, single-blinded, active-controlled trial with a 1:1 allocation ratio. The study was approved by the Suleyman Demirel University, Faculty of Medicine, Clinical Research Ethics committee (04.06.2014/96). The inclusion criteria for participants were as follows: (1) mandibular anterior dental crowding (Little's Irregularity Index [LII] > 6 mm); (2) 12 to 18 years of age; (3) permanent dentition; (4) treatment requiring no extraction of premolars or any other teeth; (5) skeletal and dental Class I relationships; (6) normal overjet and overbite; and (7) systemically and periodontally healthy. The exclusion criteria were as follows: (1) unwilling to be assigned to any of the treatment options; (2) caries and impacted or missing teeth except for third molars; (3) orthodontic treatment history; (4) posterior crossbite; (5) craniofacial syndrome or skeletal asymmetry; and (6) periodic non-steroidal anti-inflammatory drug use. Written informed consent was obtained from all study participants and their parents before the study was carried out.

Interventions

The patients were divided into the NiTi group and CuNiTi group. Roth prescription brackets with a 0.018-inch (in) slot (Mini Sprint-Prescription: Roth 0.018 in; Forestadent, Pforzheim, Germany) were used in both groups. The orthodontic light-cured adhesive system used for bonding all brackets was Transbond XT (3M Unitek, Monrovia, CA, USA) (Figure 1).

In the NiTi group, a 0.014-in round NiTi wire (natural arch form, Nickel-Titanium Archwire; Ortho Organizers, Carlsbad, CA, USA) was applied as the initial archwire immediately after the bonding procedure. At the next appointment, which was scheduled 6 weeks later, the patients received a 0.016-in round NiTi wire (natural arch form, Nickel-Titanium Archwire). The next appointment was scheduled 6 weeks later, at which time the study was terminated. The total study duration was 12

https://doi.org/10.4041/kjod.2018.48.3.153

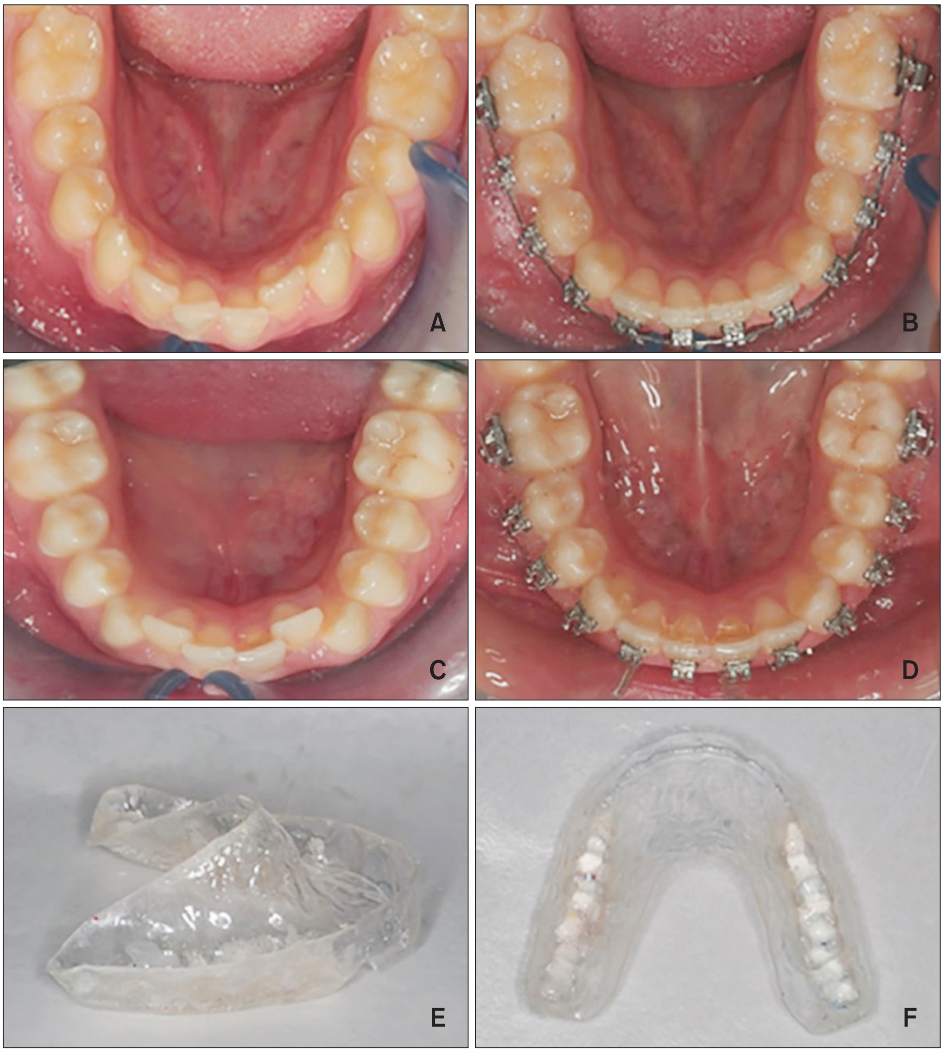

Figure 1. The appliances used in this study. **A**, Nickel-titanium (NiTi) group before treatment; **B**, NiTi group after treatment; **C**, copper-nickel-titanium (CuNiTi) group before treatment; **D**, CuNiTi group after treatment; **E**, **F**, Essix retainer with acrylic bite block.

weeks. Both archwires were tightly and fully ligated to each wing of the brackets by using ligature wires (Figure 1).

In the CuNiTi group, a 0.014-in round Tru-Arch CuNiTi 27°C (mandibular–small; Ormco Corp., Glendora, CA, USA) was applied as the initial archwire immediately after the bonding procedure. The next appointment was scheduled 6 weeks later, at which time the patients received a 0.016-in round Tru-Arch CuNiTi 27°C (mandibular–small). The next appointment was scheduled 6 weeks later, when the study terminated. The total study duration was 12 weeks. Both archwires were tightly and fully ligated to each wing of the brackets by using ligature wires.

To avoid occlusal interferences that may occur during the study, a thermoplastic retainer with an acrylic bite block (2 mm) in the premolar-molar region was applied to the upper jaw from the beginning to the end of the study in each patient (Figure 1). Patients were asked to wear these retainers at all times except mealtimes. All clinical procedures were carried out by the same clinician (BA).

All patients underwent scanning at the beginning of the study (T0) and at the 2nd (T1), 4th (T2), 6th (T3), 8th (T4), 10th (T5), and 12th (T6) weeks of treatment by using a three-dimensional (3D) intraoral scanner (TRIOS; 3Shape, Copenhagen, Denmark). The parameters measured in this study were evaluated using 3D digital casts obtained at 2-week intervals by using a 3D software program (OrthoAnalyzer; 3Shape).

The amount of alignment achieved during the study using each different archwire was measured according to LII. In the assessment of LII, each 3D dental cast was measured three times, and the mean value of the measurements was recorded (Figure 2A). The length of the arch perimeter between the mandibular canines and mandibular first molars was measured to evaluate the changes in the anterior arch perimeter and total

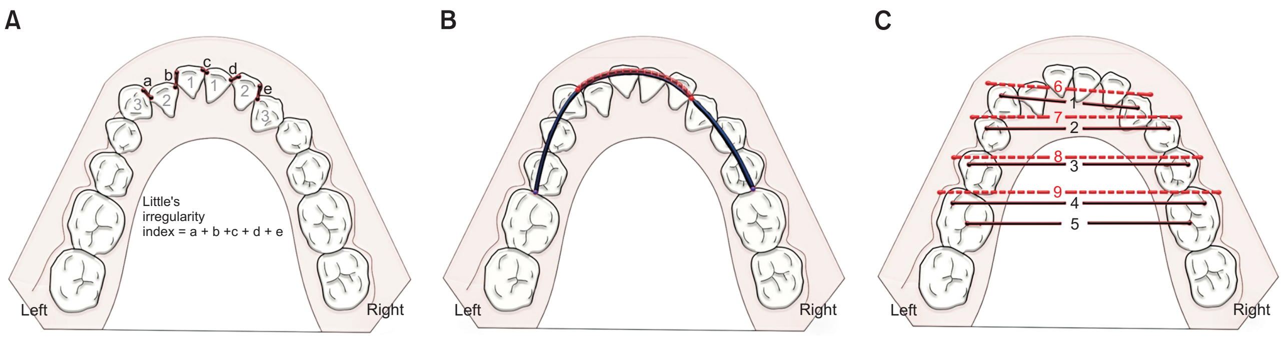

Figure 2. Dental arch measurements. A, Little's Irregularity Index. a, The distance between the mesial tip of the left canine and the distal point of the left lateral incisor; b, the distance between the mesial point of the left lateral incisor and the distal point of the left central incisor; c, the distance between the mesial point of the left central incisor and the mesial point of the right central incisor; d, the distance between the distal point of the right central incisor and the mesial point of the right lateral incisor; e, the distance between the mesial tip of the right canine and the distal point of the right lateral incisor. **B**, Intermolar and intercanine arch perimeters on mandibular dental models. Intermolar arch perimeter (solid line), the distance in millimeters from the mesial dental contact of the left first molar to the mesial dental contact of the right first molar through the dental arch. Intercanine arch perimeter (dashed line), the distance in millimeters from the mesial contact of the left canine to the mesial dental contact of the right canine through the dental arch. **C**, Interdental and interalveolar arch widths on mandibular dental models. 1, The linear distance between the cusp tips of the right and left canines; 2, the linear distance between the buccal cusp tips of the right and left first premolars; 3, the linear distance between the buccal cusp tips of the right and left second premolars; 4, the linear distance between the mesiobuccal cusp tips of the right and left first molars; 5, the linear distance between the fossa of the first molars; 6, the linear distance between the alveolar bases of the right and left canines; 7, the linear distance between the alveolar bases of the right and left first premolars; 8, the linear distance between the alveolar bases of the right and left first premolars; 9, the linear distance between the alveolar bases of the right and left first molars.

Table 1. Distributions of observed broken brackets in the two groups during the study period

Week	Arch diameter (inch)	Group	
		NiTi	CuNiTi
0–2	0.014	2	3
2–4		2	1
4–6		3	2
6–8	0.016	3	2
8–10		2	3
10–12		4	2

NiTi, Nickel-titanium; CuNiTi, copper-nickel-titanium.

arch perimeter resulting from the treatment (Figure 2B). Interdental and interalveolar measurements were performed using the abovementioned 3D software program to evaluate the transversal arch width changes resulting from the treatment using different archwires (Figure 2C).

Outcomes and changes after trial commencement

The main outcome measure of this study was the alignment of the mandibular anterior dentition, achieved using sequentially applied round archwires over 12 weeks. The secondary outcome measure was the change in mandibular dental arch dimensions. The first initial archwire applied was a 0.014-in round archwire; after 6 weeks, the archwire was changed to a 0.016-in round archwire in both groups. During the 12-week study period, the changes were recorded using a 3D digital intraoral scanner at 2-week intervals. Using computer software, the irregularity index and mandibular arch dimensions were measured for each of the 3D digital dental models obtained at 2-week intervals for 12 weeks. The archwires used in the NiTi and CuNiTi groups were (M_{stab}) NiTi and (M_{act}) CuNiTi, respectively.

All patients were clinically examined every 2 weeks, and the mandibular dental arch of each patient was scanned using an intraoral 3D scanner. Their complaints were also addressed where necessary. Patients were recalled after 1 to 3 days in case of broken brackets (Table 1). New brackets were bonded to teeth by using the same bonding materials and techniques. No changes in outcome were observed after study commencement.

Sample size calculation

In this study, a preliminary calculation was performed to calculate the sample size by using G*Power software

https://doi.org/10.4041/kjod.2018.48.3.153

version 3.0.10 (Franz Faul Universität, Kiel, Germany). To achieve 95% power, the study included 36 patients per group (for alveolar inter-first molar width feature; mean, 50 mm; standard deviation, 0.35; alpha level, 0.05).

Randomization

This study used the volunteer sampling method. The two study groups were designated using simple randomization (coin method), with an allocation ratio of 1:1 according to the type of NiTi archwire. The NiTi group, comprising 26 women and 10 men, was treated using NiTi archwires, while the CuNiTi group, comprising 20 women and 10 men, was treated using CuNiTi (27°C) archwires.

Blinding

During the single-blind study, the allocation of wires was concealed from the participants, but the clinician had this information. No other wire was used, and no other treatment was performed on the maxilla or mandible throughout the study.

Statistical analysis

Data were processed using IBM SPSS Statistics ver. 23.0 (IBM Corp., Armonk, NY, USA). The normal distribution of data was assessed using the Kolmogorov-Smirnov Z-test, and a normal distribution was found for all features. A Levene test of homogeneity was used to determine whether the distribution was similar in the groups. The data were analyzed using repeated measures of a variance analysis technique by using a factorial system (rANOVA). Repeated measures were performed in levels of wire diameter and week. In this study, the application factor had two levels (NiTi and CuNiTi); the archwire diameter factor had two levels (0.014 in and 0.016 in); and the week factor had three levels (2, 4, and 6). In order to determine the exact differences between the NiTi and CuNiTi groups in these time intervals, the covariant adjustment was calculated for the initial value of each measurement. The starting points of the means for each group were also equalized. Turkey's method was used for post hoc comparisons, and values of $p < 0.05$ were considered significant. After a 2-week interval, 20 study models were randomly selected and re-measured for reproducibility of the measurements (r: Cronbach's alpha, 0.871–0.963).

RESULTS

Volunteer inclusion began in October 2014 and ended in August 2015. When the volunteer groups were composed, 80 patients fulfilling the criteria were assessed for eligibility. After the randomization of 76 subjects to the NiTi and CuNiTi groups for the study

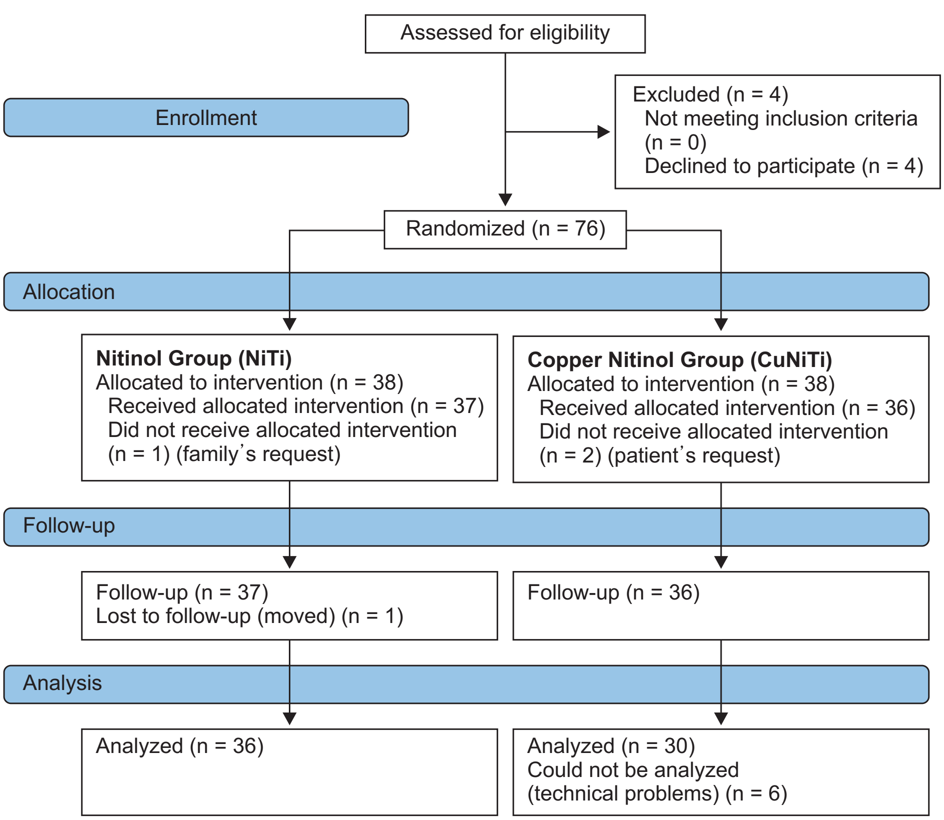

Figure 3. Flow diagram showing patient selection during the study.

with a 1:1 allocation ratio, the treatment protocol was carried out. However, at the end of the study, the data of only 66 subjects (46 females and 20 males) were analyzed (Figure 3).

Since differences were found between the groups according to baseline irregularity index values, a covariant adjustment was calculated for the initial value of each measurement. The distributions of the chronologic ages of the study participants and treatment durations for the groups are given in Table 2.

No statistically significant three-way interaction was observed between week × diameter × application types in terms of LII ($p > 0.05$). The length of the arch perimeter between the canines and the length of the arch perimeter between the first molars were significantly higher in the CuNiTi group than in the NiTi group in terms of the main effect (application factor) ($p < 0.001$). A statistically significant three-way interaction was observed between week × diameter × application types in terms of the inter-first premolar width change. When this interaction was evaluated (a) in terms of weeks (capitals, right-hand side; Table 3), the mean values obtained using the 0.014-in NiTi archwire in the second and fourth weeks of application ($p > 0.05$) were lower than those obtained in the sixth week ($p < 0.05$). For the 0.016-in NiTi archwire, the mean values obtained in the second week were lower than those obtained in the fourth and sixth weeks. The mean values obtained using the 0.014-in CuNiTi archwire in the second week were significantly lower than those obtained in the fourth and sixth weeks ($p < 0.01$). (b) In terms of diameter (lower case, right-hand side; Table 3), for the NiTi group, the mean values obtained using the 0.014-in archwires were significantly lower than those obtained using the 0.016-in archwires in the second, fourth, and sixth weeks ($p < 0.05$). For the CuNiTi group, the mean values obtained using the 0.014-in archwires were lower than those obtained using the 0.016-in archwires in the second, fourth, and sixth weeks ($p < 0.05$). (c) In terms of application (lower case, left-hand side; Table 3), the mean values obtained for the 0.014-in archwire application were statistically higher in the NiTi group than in the CuNiTi group in the second week ($p < 0.05$); however, these were statistically lower in the fourth week. In the sixth week, the mean values obtained in the NiTi group were statistically higher than those obtained in the CuNiTi group ($p < 0.05$). The mean values obtained using 0.016-in archwire application were significantly lower in the NiTi group than in the CuNiTi group in the second week ($p < 0.05$); however, these were significantly higher in the fourth week. In the sixth week, the mean values obtained in the NiTi group were significantly lower than those obtained in the CuNiTi group ($p < 0.05$).

DISCUSSION

In this study, NiTi and CuNiTi archwires on the mandibular arch were compared *in vivo* to determine the efficiency of alignment and the changes in intermaxillary arch dimension by randomizing 66 patients between two different NiTi groups.

Initial crowding evaluated using LII was 10.24 ± 2.10 mm and 10.60 ± 2.43 mm, respectively, for the NiTi and CuNiTi groups. The total amount of alleviation of crowding with the sequential (6 weeks for each archwire) application of 0.014-in and 0.016-in archwires was 4.07 mm in the NiTi group and 3.58 mm in the CuNiTi group. In this study, the NiTi and CuNiTi archwires showed statistically non-significant results in terms of the alleviation of crowding. These results are compatible with those of other studies.[11,12,14] Our study groups included patients with severe crowding. However, our result is similar to that of studies on groups with severe and/or moderate crowding.[11,12,14] Previous studies have demonstrated that during the alleviation of crowding under both moderate and severe crowding conditions, NiTi wires provide successful treatment results with preadjusted edgewise appliances.[21]

The arch perimeter, measured parallel to the occlusal plane, was affected by the protrusion of the incisors. The ligation of malposed teeth to the archwire without space-gaining methods could cause forced (obligatory) labial/buccal tipping, which could result in protrusion or dental expansion. This protrusion may be more evident in the anterior region, since crowding often occurs in this region. Moreover, the weaker roots of the anterior teeth predispose them to dental tipping.

Table 2. Active treatment duration and age distributions of participants in the study groups

	Group	
	NiTi (n = 36)	CuNiTi (n = 30)
Age (yr)	14.71 ± 1.79 (12–16)	15.86 ± 1.58 (13–17)
Active treatment duration (d)	89.75 ± 6.58 (83–108)	90.93 ± 7.48 (83–120)

Values are presented as mean ± standard deviation (range).
NiTi, Nickel-titanium; CuNiTi, copper-nickel-titanium.

Table 3. Descriptive statistics, covariance values, and alignment characteristics over the treatment duration in the NiTi and CuNiTi groups

Variable	Group	T0 Week 0	Covariance value	0.014-in round arch wire			0.016-in round arch wire			p-value		
				T1 Week 2	T2 Week 4	T3 Week 6	T4 Week 8	T5 Week 10	T6 Week 12	WDA	DA	A
LII	Niti	10.24 ± 2.10	10.40	8.45 ± 0.22	7.57 ± 0.24	6.93 ± 0.23	6.50 ± 0.27	6.41 ± 0.24	6.33 ± 0.27	NS	NS	NS
	CuNiTi	10.60 ±.2.43		8.22 ± 0.24	7.83 ± 0.27	7.09 ± 0.26	6.85 ± 0.30	6.88 ± 0.27	6.82 ± 0.30			
Intercanine arch perimeter	Niti	38.36 ± 2.25	38.49	37.84 ± 0.41	38.66 ± 0.35	38.31 ± 0.37	38.66 ± 0.35	39.31 ± 0.42	39.25 ± 0.46	NS	NS	†
	CuNiTi	38.66 ± 2.53		39.44 ± 0.46	39.96 ± 0.35	40.50 ± 0.41	39.96 ± 0.35	41.25 ± 0.48	41.61 ± 0.52			
Intermolar arch perimeter	Niti	69.12 ± 2.91	69.11	68.81 ± 0.34	69.73 ± 0.40	69.17 ± 0.37	69.73 ± 0.40	71.17 ± 0.72	70.73 ± 0.47	NS	NS	†
	CuNiTi	69.11 ± 3.44		70.24 ± 0.38	70.77 ± 0.36	71.67 ± 0.42	72.29 ± 0.46	72.61 ± 0.81	73.13 ± 0.54			
Intercanine width	Niti	25.64 ± 2.64	25.66	26.56 ± 0.25	26.61 ± 0.26	27.03 ± 0.25	26.48 ± 0.23	26.90 ± 0.26	27.10 ± 0.26	NS	NS	NS
	CuNiTi	25.69 ± 1.87		26.12 ± 0.28	26.82 ± 0.29	27.09 ± 0.28	26.65 ± 0.26	26.85 ± 0.29	27.29 ± 0.29			
First premolar width	Niti	32.82 ± 2.29	32.71	[a]33.35[Bb] ± 0.18	[b]33.40[Bb] ± 0.24	[a]33.98[Ab] ± 0.24	[b]34.42[Ba] ± 0.29	[a]35.08[Aa] ± 0.31	[b]35.00[Aa] ± 0.24	*	NS	NS
	CuNiTi	32.56 ± 2.11		[b]33.32[Bb] ± 0.21	[a]34.10[Ab] ± 0.27	[b]33.96[Ab] ± 0.27	[a]34.67[Aa] ± 0.32	[b]34.71[Aa] ± 0.35	[a]35.08[Aa] ± 0.27			
Second premolar width	Niti	38.14 ± 2.60	38.10	38.59 ± 0.26	38.97 ± 0.19	39.41 ± 0.21	39.60 ± 0.34	39.77 ± 0.35	40.25 ± 0.26	NS	NS	NS
	CuNiTi	38.05 ± 2.57		38.63 ± 0.30	39.38 ± 0.21	39.17 ± 0.24	39.87 ± 0.38	39.83 ± 0.40	40.36 ± 0.30			
First molar fossa width	Niti	42.10 ± 2.80	42.67	43.11 ± 0.29	42.82 ± 0.18	42.86 ± 0.17	43.03 ± 0.21	42.54 ± 0.30	42.93 ± 0.25	NS	NS	NS
	CuNiTi	41.52 ± 3.26		42.56 ± 0.32	42.93 ± 0.20	42.93 ± 0.20	43.18 ± 0.23	42.88 ± 0.34	42.95 ± 0.28			
Intermolar width	Niti	42.71 ± 2.84	41.84	41.76 ± 0.17	41.68 ± 0.18	41.65 ± 0.18	41.55 ± 0.21	41.50 ± 0.21	41.68 ± 0.28	NS	NS	NS
	CuNiTi	42.63 ± 2.61		41.37 ± 0.19	41.66 ± 0.20	41.56 ± 0.20	41.80 ± 0.24	41.98 ± 0.23	41.46 ± 0.32			
Alveoar intercanine width	Niti	30.16 ± 2.08	30.26	29.80 ± 0.17	29.61 ± 0.20	29.89 ± 0.18	29.90 ± 0.20	30.17 ± 0.21	30.26 ± 0.27	NS	NS	NS
	CuNiTi	30.16 ± 2.08		29.78 ± 0.19	30.12 ± 0.24	30.03 ± 0.20	30.11 ± 0.23	30.34 ± 0.24	30.60 ± 0.31			
Alveolar first premolar width	Niti	39.47 ± 2.14	39.39	37.80 ± 0.19	37.76 ± 0.20	38.44 ± 0.20	38.53 ± 0.20	38.60 ± 0.30	39.08 ± 0.25	NS	NS	NS
	CuNiTi	39.30 ± 2.28		37.84 ± 0.22	38.39 ± 0.22	38.39 ± 0.23	38.82 ± 0.22	38.93 ± 0.33	39.13 ± 0.28			
Alveolar second premolar width	Niti	45.75 ± 2.24	45.53	43.62 ± 0.31	43.46 ± 0.26	43.88 ± 0.26	44.34 ± 0.27	44.36 ± 0.28	44.60 ± 0.30	NS	NS	NS
	CuNiTi	45.25 ± 2.82		43.80 ± 0.35	44.43 ± 0.30	44.42 ± 0.29	44.71 ± 0.30	44.75 ± 0.32	44.78 ± 0.34			
Alveolar first molar width	Niti	53.38 ± 2.57	53.25	50.02 ± 0.39	49.81 ± 0.30	49.78 ± 0.28	49.81 ± 0.44	50.18 ± 0.34	50.06 ± 0.31	NS	NS	NS
	CuNiTi	53.07± 3.37		49.67 ± 0.31	50.72 ± 0.20	49.58 ± 0.36	50.00 ± 0.35	50.30 ± 0.23	49.87 ± 0.40			

Values are presented as mean ± standard deviation.
NiTi, Nickel-titanium; CuNiTi, copper-nickel-titanium; LII, Little's Irregularity Index; WDA, week × diameter × application; DA, diameter × application; A, application; NS, not significant.
T0, pretreatment; T1, 0.014 inch (in) round arch wire's 2nd week; T2, 0.014-in round arch wire's 4th week; T3, 0.014-in round arch wire's 6th week; T4, 0.016-in round arch wire's 2nd week; T5, 0.016-in round arch wire's 4th week; T6, 0.016-in round arch wire's 6th week.
Three-way interactions between WDA types are indicated with letters; capital letters on the right side indicate differences in terms of weeks; lowercase letters on the right side indicate differences in terms of diameter; lowercase letters on the left side indicate differences in terms of application.
No statistically significant differences are observed between the means with the same letters ($p > 0.05$); *$p < 0.05$; †$p < 0.001$ (rANOVA value).

Insufficient occlusal contacts, which can limit dental tipping unlike in the posterior teeth, could be the reason for the shift of this protrusion through the anterior region.[22] In our study, the mean values for the intercanine arch perimeter were higher in the CuNiTi group than in the NiTi group (p < 0.01) from the second week. The covariates were adjusted for initial values of all examined parameters. This difference in intercanine arch perimeter appeared at the end of the second week and remained until the end of the study. The application of CuNiTi archwires involves stronger forces than does the application of NiTi wires, and they exhibit rapid hardening in the oral environment because of their alloy structure.[23] This difference in intercanine arch perimeter may be attributed to the anterior teeth in the CuNiTi group protruding faster as a result of the archwire alloy structure. Hence, both NiTi and CuNiTi archwires have similar effects on the alleviation of crowding and expansion of the intercanine arch width. The significantly increased changes in the CuNiTi group than in the NiTi group in terms of the length of the intercanine arch perimeter show that this group may have a greater tendency towards protrusion, which is a risk factor for stability.[24] Some studies have suggested an increase in arch perimeter after non-extraction orthodontic treatment in patients with Class I malocclusion.[22,24]

For the intermolar arch perimeter, the mean values obtained using CuNiTi archwires were significantly higher than those obtained using NiTi archwires (p < 0.01). Moreover, this measurement showed higher values in the CuNiTi group throughout the treatment protocol. This result was also compatible with the increase in intercanine arch perimeter.

The shape of the mandibular arch is in structural and functional harmony.[25] During orthodontic treatment, the prevention of intercanine arch width changes could increase the long-term success in terms of retention.[26] In this study, no statistically significant difference was observed between the groups in intercanine arch width (p > 0.05). The increases in intercanine width were 1.44 mm in the NiTi group and 1.63 mm in the CuNiTi group. Previous studies have reported increases in intercanine widths of between 0.54 and 1.96 mm.[22,24,25] However, studies have also reported that this increase in width was lost after the retention period.[25] This suggests that the risk of relapse, which could occur after treatment in both the groups, should be evaluated in further studies.

A statistically significant three-way interaction (week × diameter × application) was noted between the groups in terms of the inter-first premolar width (p < 0.05). The increase in inter-first premolar width for the 0.014-in NiTi archwire in the sixth week was more significant than that in the second and fourth weeks (p < 0.05). For the 0.016-in NiTi archwire, the increases in arch width in the fourth and sixth weeks were similar and significantly more evident than those in the second week (p < 0.05). The interdental width obtained at the end of the fourth and sixth weeks with the 0.014-in CuNiTi archwire was more statistically significant than that obtained at the end of the second week (p < 0.05). For the 0.016-in CuNiTi archwire, the increase obtained at the end of the second, fourth, and sixth weeks was not statistically significant (p > 0.05) (capitals, right-hand side; Table 3). As the study progressed, an increase in arch width was obtained for both types of archwires. Studies evaluating the changes in intercanine, interpremolar, and intermolar widths after fixed orthodontic treatment have reported that the most notable difference was observed in the premolar region.[22,26] The first reason for this could lie in the arch form (Figure 4) of the archwires used in the study. It has been revealed that during the leveling and aligning phases of treatment, the Tru-Arch archwires, which were used in this study, could produce statistically significant increases in the transverse dentoalveolar width and the perimeter of the maxillary arch.[27] As the forms of arches used in this study were similar to each other (Figure 4), the obtained changes in arch widths were an expected conclusion. The second reason could be the eruption path of the first premolar teeth in the lingual direction.[22] The application of orthodontic forces to the lingually erupted premolars from the buccal side may have caused more dramatic changes in this region.

In this study, the inter-first premolar width measurements were statistically higher in the NiTi group than

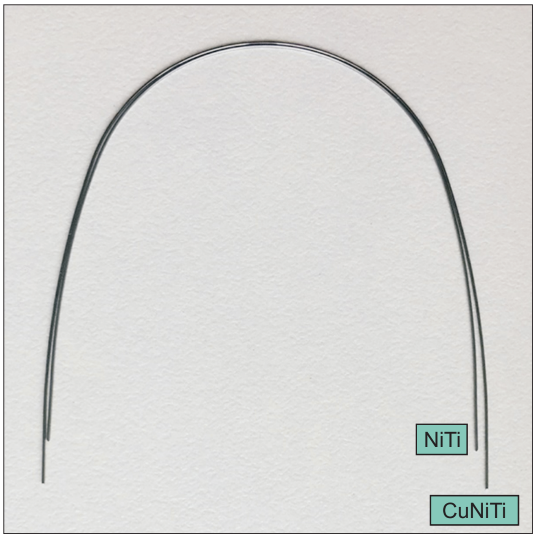

Figure 4. The arch forms of nickel-titanium (NiTi) and copper-nickel-titanium (CuNiTi) archwires used in this study.

in the CuNiTi group at the end of the second week; these were reversed in the next period, and this pattern repeated until the end of the study. This could be explained by the increase in the length of the intercanine arch perimeter in the lower anterior region at the end of the second week in the CuNiTi group. In the first week of application of the CuNiTi archwires, the rapid hardening of the wire in conjunction with the influence of its mechanical properties may have caused protrusions in the anterior region, where the roots were weaker than in the posterior teeth, rather than contributing to the increase in transversal arch width. The reversal of this pattern in the fourth week, where the CuNiTi archwire caused transversally greater expansion in the premolar region, suggests that CuNiTi had started expanding the arch after a sudden protrusion in the first week. In the sixth week, the pattern again favored the NiTi group, and this was maintained in the following weeks.

Studies evaluating the changes in inter-first premolar width in fixed orthodontic treatment have shown that the results obtained vary between 1.46 and 3.22 mm because of the differences in materials and methodology.[24,28] In contrast to the results of our study, Fleming et al.[24] found no statistically significant increase in inter-first and inter-second premolar width changes before and after fixed orthodontic treatment at the leveling stage. The reason for this difference could be the difference in the design materials and methods.

The changes in interalveolar widths evaluated in this study were statistically non-significant ($p > 0.05$). Lundström[29] has shown that the apical base is not affected by orthodontic tooth movement and mastication. Additionally, alveolar buccal changes do not follow dental expansion.[28] Since neither group showed changes in alveolar widths, this is considered a favorable factor for retention.[30]

In this single-center study, the treatments were performed by a single clinician. Thus, the generalizability of the results of this study may be limited.

CONCLUSION

- The effects of sequentially applied 0.014-in and 0.016-in NiTi and CuNiTi round archwires were similar in terms of their alignment efficiency in the mandibular anterior region.
- In the second week of use of the 0.014-in archwire, the intercanine arch perimeter and total arch perimeter increased in the CuNiTi group than in the NiTi group. This difference due to the increased value of the arch perimeters was maintained during the study period.
- A statistically significant difference was obtained using a three-way interaction between week × diameter × application types in terms of the inter-first premolar width change. The transverse interpremolar arch widths increased with both 0.014-in and 0.016-in sequentially applied CuNiTi round archwires than with similarly applied NiTi round archwires.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGEMENTS

This study was funded by Suleyman Demirel University Scientific Research Projects Foundation (project No. 4243- D2-15).

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https://doi.org/10.4041/kjod.2018.48.3.153