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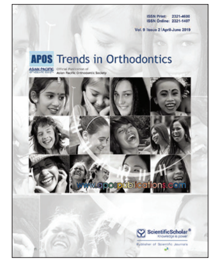

Original Article

Evaluation of root resorption of mandibular anterior teeth at the end of stage I with three different alignment archwires

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ABSTRACT

Objectives: To evaluate external apical root resorption (EARR) and alignment time using three different alignment archwires at the end of alignment stage with CBCT.

Material and Methods: 66 patients seeking orthodontic treatment were selected with inclusion criteria of moderate crowding in the mandibular arch and extraction of mandibular first premolars, equally divided into three groups (n = 22 per group) as follows: Group I – Copper Ni-Ti (CuNiTi) 37°C, Group II – Superelastic NiTi, and Group III – Nitinol classic. The study was started on those samples with fixed appliances (MBT prescription – 0.022 slot). CBCT images of six mandibular anterior teeth were taken before and after the completion of 4 weeks of 0.019-inch × 0.025-inch NiTi in each of the groups. Root length was determined using axial-guided navigation, and root volume was measured using ITK SNAP software. The alignment efficiency is measured, which is usually a passive engagement of a rectangular 0.019 × 0.025 NiTi wire in the slots of the attachments from the molar to the contralateral molar.

Results: There was a significant reduction in average root length and volume in three groups. However, the reduction in average root length and volume after post-alignment was comparatively less significant in the CuNiTi group. The time span for alignment was significantly different between the groups, with the highest time in the nitinol group (118 days) lowest time in the CuNiTi groups (105 days).

Conclusion: Root resorption was minimal with CuNiTi and maximum with conventional nitinol wires. CuNiTi exhibited superior alignment efficiency over superelastic NiTi and conventional nitinol wires.

Keywords: External apical root resorption, Nickel titanium, Root length, Root resorption, Root volume

INTRODUCTION

In the initial phase of orthodontic treatment, focusing on tasks such as crowding correction, minor tooth adjustments, alignment, and leveling, clinicians seek wires that apply light and continuous forces efficiently, minimizing treatment duration and potential damage to supporting structures.[1] Nickel titanium (NiTi) wires, particularly those with a low modulus of elasticity, have revolutionized orthodontics since their introduction. Initially described by Andreasen and Hilleman and further developed by Burstone and Miura.[2] NiTi archwires offer various advantages owing to their unique crystalline forms: Martensitic (M) and austenitic (A). These wires can be engineered to exhibit superelasticity, a property reliant on the coexistence of these phases, enabling them to absorb deflection stresses and exert consistent forces over a wide range of deflections, particularly beneficial in aligning archwires.[3] NiTi wires can be classified based on their crystal structure, phase transformation, and stiffness into stabilized martensitic, superelastic active austenitic, thermodynamic-active martensitic, and graded thermodynamic categories, each offering distinct force characteristics. Notably, thermodynamically active martensitic NiTi alloys, such as those incorporating copper, exhibit preset transition temperature ranges, allowing for controlled force application.[4] Copper NiTi (CuNiTi) archwires, for instance, improved shape memory, reduced hysteresis, and enhanced thermal stability, promoting faster tooth movement with lower activation loads and diminished discomfort for patients. Despite manufacturers' claims and theoretical advantages, studies reveal discrepancies in aligning efficiency and root resorption among NiTi alloys, prompting the need for comprehensive investigations.[5,6] External apical root resorption (EARR), a concern in orthodontics, necessitates accurate diagnostic tools like cone-beam computed tomography (CBCT) to assess three-dimensional changes in root surfaces. While continuous forces applied during initial alignment facilitate tooth movement, they may also exacerbate EARR, highlighting the importance of understanding how different NiTi alloys impact this phenomenon. Therefore, this study aims to evaluate and compare EARR levels associated with stabilized nitinol (high force), superelastic active austenitic NiTi (medium force), and thermodynamic-active martensitic NiTi (low force) using CBCT, filling a crucial gap in understanding the interplay between different NiTi alloy characteristics and EARR outcomes in orthodontic therapy.

MATERIAL AND METHODS

Study design

The study is a prospective, single-centered randomized clinical trial designed as a double-blinded and parallel groups with non-stratified permuted block randomization with an allocation ratio (1:1). No changes were made in methodology after trial commencement.

Participants, eligibility criteria

This study was approved by the institutional ethical committee and was conducted between 2021 and 2023 to evaluate root resorption in orthodontic treatment using different types of NiTi alloy arch wires. This trial was registered at ClinicalTrials.gov with the identifier number CTRI/2021/05/033728. Informed consent was obtained from all participants before the initiation of treatment.

Participants were selected based on specific inclusion and exclusion criteria. Inclusion criteria included patients seeking fixed appliance orthodontic treatment with moderate crowding in the mandibular arch, requiring extraction of mandibular first premolars, and having complete lower permanent dentition, excluding third molars. Exclusion criteria included previous orthodontic treatment, <6 mm of lower incisor crowding or spaced incisors, blocked-out teeth, periodontal issues, systemic conditions, continuous medication, traumatic injuries, and dental restorations.

Sample size

Sample size was determined using G*POWER3.1.9.2 software, with 66 subjects needed for 80% power at a 5% alpha level. All the participants were equally divided into three groups: Group I received CuNiTi 35°C (ORMCO, South Lone Hill, Glendora), Group II received Superelastic (3M UNITEK, Monrovia, USA), and Group III received Nitinol Classic (3M UNITEK, Monrovia, USA) with MBT Prescription-0.022 slot Mini 2000 (ORMCO, Southlone Hill, Glendora) brackets.

Randomization

Sequence generation: A computer random number generator (http://www.graphpad.com/quickcalcs/randomn2.cfm) was used to develop a simple non-stratified randomization with an equal allocation ratio (1:1). Each number in the resultant random table was given a study number by an independent person to develop the Allocation Table, which included the study number and allocation group for the participants. The Allocation Table was the only document that could unmask the groups, so it was kept sealed away from the investigators until the completion of data measurement and analysis.

After recruiting patients who met the inclusion criteria, the participants were randomly allocated using the permuted random block technique with a 1:1:1 allocation ratio by a third person who is not associated with the research. The allocation sequence was concealed from the researcher by sequentially numbered, opaque, sealed, and stapled envelopes before the intervention. All the trial documents were labelled with the study ID number, which was used for participant identification and data collection without unmasking the allocation group. This allowed the investigator to complete data collection and measurements blindly. The outcome assessor, participants, and the statistician were blinded; however, the operator could not be blinded to the allocation groups because the clinicians could know the type of archwires from their flexibility.

Intervention

The study utilized the straight wire technique with MBT Prescription-0.022 slot brackets, and subjects were reviewed at 4-week intervals and the average sequence of wires will be as follows: 0.012-inch, 0.014- inch, 0.018-inch, 0.016 inch × 0.022-inch, 0.017 inch × 0.025-inch, and 0.019-inch × 0.025-inch NiTi wires on a 0.022-inch slot in each group. CBCT images of 6 mandibular anterior teeth were taken before and after orthodontic alignment to analyze the root length and root volume. The images were examined using Xoran 3.1.62 software. To assess alignment efficiency, mandibular impressions were taken and study models were prepared at the beginning of fixed orthodontic treatment and thereafter every month till the completion of alignment.

Primary outcome methodology

Evaluation of root length

To analyze EARR using CBCT in mandibular anterior teeth, the linear length between the root apex and cementoenamel junction (CEJ) was measured by a single examiner. The maximum linear length between CEJ and root apex was measured using axial multiplanar reconstruction at a 0.25-mm isometric voxel, which is based on an axial-guided navigation technique.[7] The axial movement of the cursor on sagittal or coronal multiplanar reconstruction defined the reference points [Figures 1-3].

The distance between the reference points was marked in the sagittal or coronal multiplanar reconstruction, providing measurements in millimeters [Figure 4]. EARR was measured before and after levelling and alignment, and data were recorded using Microsoft Office ExcelTM 2007.

Evaluation of root volume

Digital Imaging and Communications in Medicine datasets were imported into ITK-Snap software (version 3.2, http://www.itksnap.org) to generate stereolithographic (STL) data [Figure 5]. The radiographer assigned a number to each STL image; the primary investigator (P.P.) was blinded to the codes. The corresponding STL images for T0 and T1 were imported into Geomagic (Geomagic, Cary, N.C.).

The reference plane was constructed between the highest point of the labial and palatal CEJ. T0 to T1 STL images were segmented immediately below the reference plane, and the root portion was analyzed.[8] Root volumes were computed using Geomagic software [Figure 6].

Secondary outcome methodology

Alignment efficiency

The alignment efficiency is measured by the time taken for the completion of the preliminary clinical levelling phase of treatment, which is usually a passive engagement of a rectangular 19 × 25 NiTi wire in the slots of the attachments from the molar to the contralateral molar. The incisal edges of the anterior teeth and the buccal cusps of posterior teeth are at the same horizontal level, and the teeth are lined up in an arch form by the completion of the Alignment phase of mechanotherapy.

RESULTS

Statistical analysis

Data were analyzed using IBM Statistical Package for the Social Sciences (SPSS) version 20 software (IBM SPSS, IBM Corp., Armonk, NY, USA). Descriptive statistics, Kolmogorov–Smirnov tests for assessing the normality of study data, one-way analysis of variance, Chi-square test, Wilcoxon signed-rank tests, Kruskal–Wallis analysis of variance, and Friedman's tests were performed. Bar charts were used for data visualization. Non-parametric tests were primarily used, except for the variables age, time span for alignment, and Little's irregularity index, which followed a normal distribution based on the Kolmogorov–Smirnov test ($P \leq 0.05$). $P \leq 0.05$ was considered statistically significant [Table 1].

Participant flow

A total of 66 patients were invited to participate in the study, with 22 participants each in the CuNiTi group, superelastic NiTi group, and nitinol group. The participant flow is

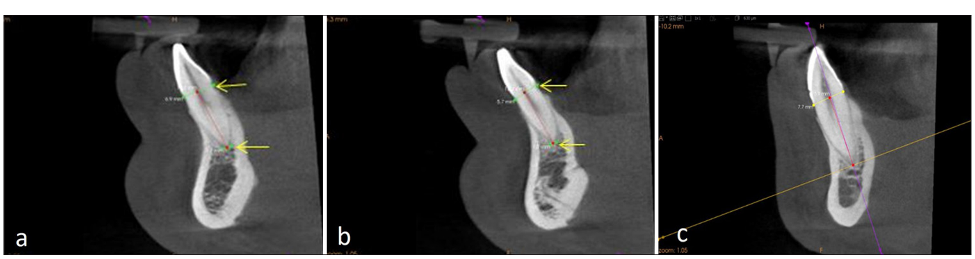

Figure 1: Reference points Cemento enamel junction(CEJ) to Root apex (yellow colour arrows) to measure linear length (red line) (a) Reference points to measure linear length (CEJ to Root apex) on central incisor; (b) Reference points to measure linear length (CEJ to Root apex) on lateral incisor; (c) Reference points to measure linear length (CEJ to Root apex) on canine.

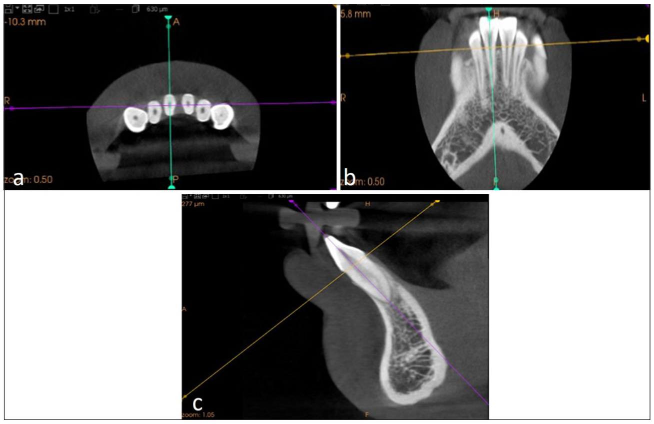

Figure 2: Axial multiplanar reconstruction with identification of cementoenamel junction (CEJ) as a reference point. (a) Coronal (b) sagittal (c) multiplanar reconstruction identifies CEJ at the intersection of the axial cursor with coronal and sagittal cursors.

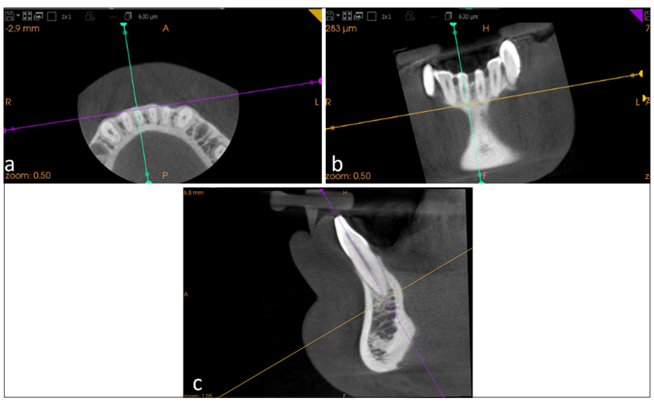

Figure 3: Axial multiplanar reconstruction with identification of root apex as reference points. (a) Coronal (b) sagittal (c) multiplanar reconstruction identifies the root apex at the intersection of axial cursor with coronal and sagittal cursors.

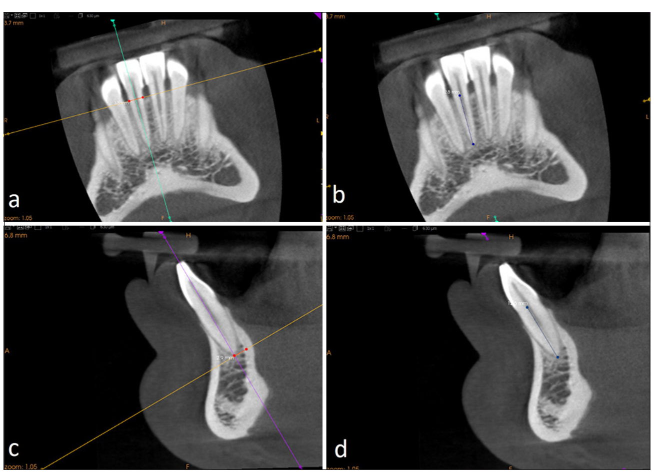

Figure 4: Tracing with CBCT software measuring tool on (a and b) sagittal and (c and d) coronal.

depicted in the consolidated standards of reporting trials (CONSORT) flowchart [Figure 7].

Baseline data

Kolmogorov–Smirnov tests confirmed that the data were normally distributed ($P > 0.05$). It presents the baseline descriptive statistics of the root lengths and volumes at the start of the study (T0) for the three groups.

Primary outcome measures

Changes in root length

Descriptive statistics for changes in root length between time points T0 and T1 are summarized in [Table 2]. All three groups showed a reduction in root length over time, with the nitinol group demonstrating the highest mean reduction in root length across all teeth. For example, the mean reduction in root length for tooth 43 was highest in the nitinol group (0.709 mm), compared to 0.504 mm in the superelastic NiTi group and 0.372 mm in the CuNiTi group.

Changes in root volume

Root volume changes from T0 to T1 are detailed in [Table 3]. Similar to root length, the nitinol group showed the greatest reductions in root volume across most teeth, with tooth 41 exhibiting a mean reduction of 59.05 mm^3, compared to 40.91 mm^3 in the superelastic NiTi group and 39.09 mm^3 in the CuNiTi group.

Tooth-wise comparisons

Tooth-wise mean differences in root length and root volume across the three groups are presented in [Tables 4 and 5]. The Kruskal–Wallis test showed significant differences between groups for both root length and volume ($P < 0.05$). *Post hoc* analysis revealed that the nitinol group experienced significantly greater reductions in both parameters compared to the CuNiTi and superelastic NiTi groups.

Secondary outcome

The time span for alignment was significantly different between the groups, with the highest time in the nitinol group, followed by the superelastic NiTi group and the CuNiTi group [Table 6].

DISCUSSION

This study was designed to determine whether there are any clinical differences between nitinol, superelastic NiTi, and CuNiTi archwires in terms of root resorption and alignment efficiency. The results showed a statistically significant difference between the three types of NiTi arch wires.

Superelastic NiTi archwires need to be bent by 50–70° to effectively harness their super-elastic properties. This level of deformation is achievable in clinical settings due to the

Table 1: Basic characteristics of the three groups.

	CuNiTi	Superelastic NiTi	Nitinol	*P*-value
Gender: Male/Female in no.	10/12	10/12	10/12	1.00
Age in Years: Mean (SD)	16.0364 (1.02982)	16.1227 (1.06589)	16.1227 (1.06589)	0.952
Little's irregularity index Mean (SD)	6.977 (0.6055)	6.891 (0.5264)	7.000 (0.5944)	0.804

P-value for comparison of group means by Chi-square test and analysis of variance test. CuNiTi: Copper nickel-titanium, NiTi: Nickel-titanium, SD: Standard deviation

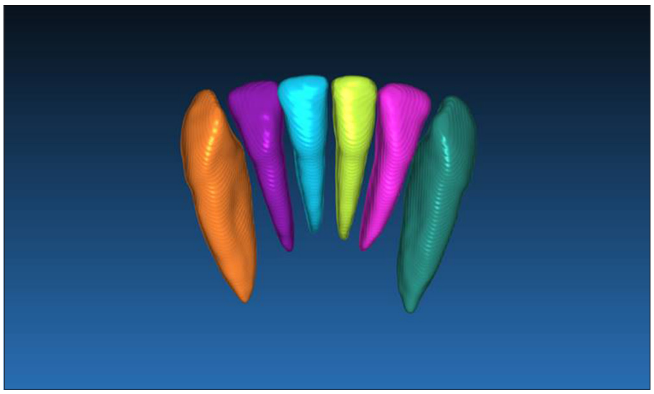

Figure 5: Three-dimensional segmentation of the lower anterior teeth.

Figure 6: Three-dimensional segmentation of individual root at the reference plane and root volume was measured.

degree of crowding and reduced interbracket distances found in lower anterior crowding cases. The main difference between superelastic and thermal wires is in the force levels. Thermally active wires produce significantly lower working forces than superelastic wires of the same size.[9,10] *In vitro* studies[11] prefer thermal wires to superelastic wires during the alignment phase because of their lower working forces and ability to express the particular characteristic of superelasticity at lower deflection levels. Moreover, these wires permit so-called "full-bracket engagement" at the start of treatment and in subjects with severe dental crowding, decreasing the risk of generating excessive forces.

In the present study, the end of the leveling phase was chosen as the time point for the evaluation of the effect of the three different arch wire materials, owing to the possibility of using only one type of arch wire material before the continuation of treatment that would require both types of arch wires. In addition, the amount of root shortening 6–12 months after bracket placement is of high predictive value for the severity of root resorption after the completion of treatment.[12] Mandibular incisors were selected for the study because they are more prone to tooth resorption, while a small reduction in their length is easy to detect using radiographic techniques.

The results of the present study reflected an overall reduction in root length and root volume in the three groups after levelling and alignment. CuNiTi showed the least root resorption, followed by superelastic NiTi and Nitinol.

The results of the current study were consistent with those of Nabbat and Yassir[13] and Alzahawi *et al.*[14] who found that lower incisors appeared to be significantly affected by root resorption in the group treated with super-elastic NiTi wires. Jain *et al.*[5] observed higher root resorption in super-elastic NiTi wires (0.59 mm) than in heat-activated NiTi (0.50 mm); however, the difference was not statistically significant. This may be related to the continuous force exerted by the super-elastic NiTi wires. Whereas, intermittent forces could produce less root resorption because the period of inactive tooth movement provides the chance for the resorbed cementum to heal. Weiland[15] stated that the perimeter, area, and volume of resorption lacunae were significantly larger (140%) when the teeth were moved with superelasticity than when they were moved with steel wires. The continuous force of 0.8-1 N used for tipping tooth movement is more detrimental than an initially higher but rapidly dissipating force. This finding underscores the importance of continuous radiographic follow-up during orthodontic treatment to monitor root resorption evaluating root resorption, especially when using superelastic NiTi and nitinol wires. The results also highlight the efficiency of thermally active CuNiTi wires in producing significantly lower working forces, which could be optimal in preserving the integrity of periodontal structures, thus minimizing root resorption during the levelling phase of mechanotherapy.

An orthodontic force can be defined as heavy or light according to the ratio between the magnitude of the force applied and the affected root–bone surface. Because of the surface area of the periodontal structure involved, an ideal archwire should be able to deliver differential forces to the arch segments.

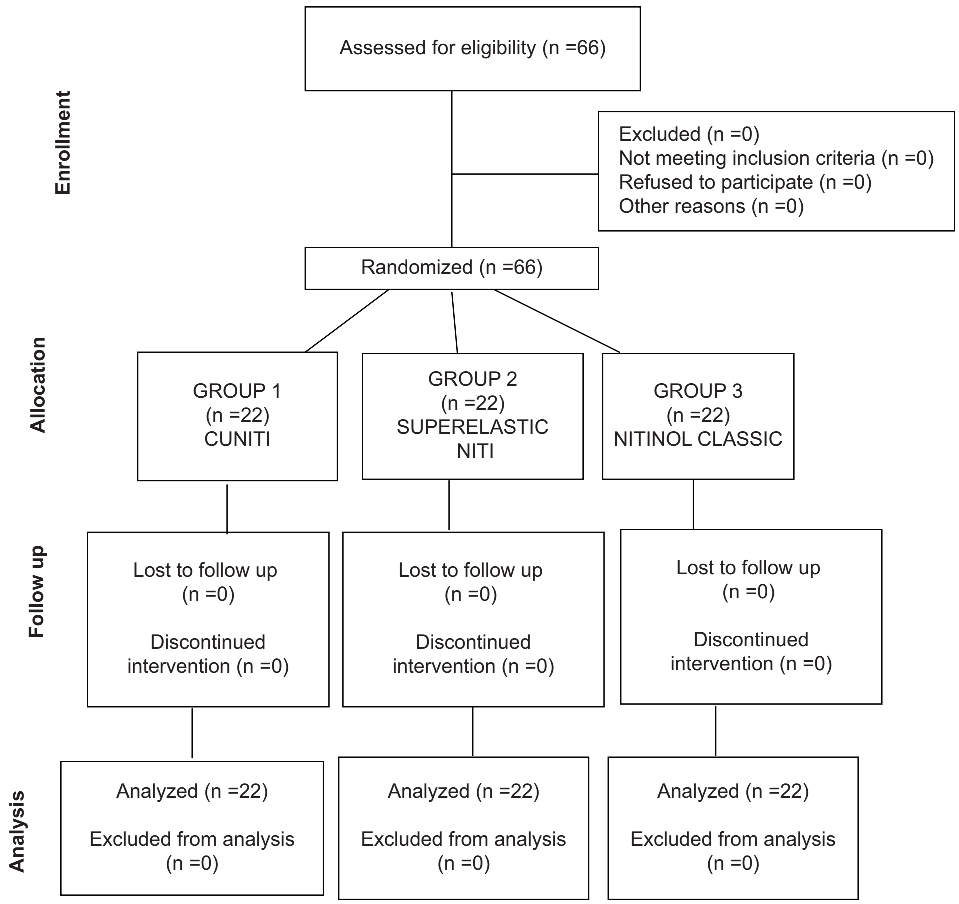

Figure 7: Consort flowchart of participants through each stage of the trial. CuNiTi: Copper nickel-titanium, NiTi: Nickel-titanium.

Table 2: Comparison of tooth-wise and average root lengths between the 2 time points in CuNiTi, superelastic NiTi, and nitinol group.

Tooth/Average	Time	CuNiTi			Superelastic NiTi			Nitinol		
		Mean	Standard deviation	*P*-value	Mean	Standard deviation	*P*-value	Mean	Standard deviation	*P*-value
43	T0	13.632	0.4612	0.038*	13.536	0.5287	0.005*	13.505	0.4981	0.002*
	T1	13.259	0.5188		13.032	0.5550		12.668	0.6312	
42	T0	12.591	0.4196	0.083	12.591	0.4185	0.02*	12.945	0.2988	<0.001*
	T1	12.423	0.3250		12.118	0.5261		12.241	0.4228	
41	T0	11.932	0.7761	0.085	11.882	0.6645	0.034*	12.227	0.8119	0.012*
	T1	11.677	0.7400		11.345	0.7321		11.727	0.7778	
31	T0	11.714	0.4279	0.008*	11.795	0.3199	<0.001*	11.773	0.2931	<0.001*
	T1	11.500	0.3854		11.264	0.2441		11.323	0.2092	
32	T0	12.377	0.4566	0.034*	12.350	0.5405	0.003*	12.300	0.4821	0.003*
	T1	12.159	0.4827		11.786	0.5609		11.745	0.6108	
33	T0	13.764	1.2211	0.239	13.309	0.9133	0.034*	13.714	0.4074	<0.001*
	T1	13.445	1.2015		12.727	0.9468		13.005	0.3124	
Average	T0	12.6673	0.33884	0.013*	12.5782	0.28455	<0.001*	12.7436	0.18009	<0.001*
	T1	12.4114	0.32193		12.0445	0.35219		12.1186	0.13145	

Wilcoxon signed-rank test, *denotes statistical significance. CuNiTi: Copper nickel-titanium, NiTi: Nickel-titanium

Table 3: Comparison of toothwise and average root volume between the 2 time points in CuNiTi, Superelastic NiTi, and nitinol group.

Tooth	Time	CuNiTi			Superelastic NiTi			Nitinol		
		Mean	Standard deviation	*P*-value	Mean	Standard deviation	*P*-value	Mean	Standard deviation	*P*-value
43	T0	481.86	10.311	<0.001*	477.68	13.674	<0.001*	467.41	17.306	<0.001*
	T1	446.05	5.085		431.45	15.420		414.27	15.545	
42	T0	435.73	26.350	<0.001*	408.05	47.409	0.054	451.32	18.339	<0.001*
	T1	409.36	22.214		376.45	55.252		407.50	15.826	
41	T0	371.45	50.759	0.013*	355.41	42.432	0.002*	374.05	15.610	<0.001*
	T1	332.36	60.450		314.50	50.488		315.00	50.386	
31	T0	375.36	15.598	<0.001*	361.64	11.358	<0.001*	374.77	12.444	<0.001*
	T1	350.86	14.717		331.14	15.914		342.00	11.002	
32	T0	408.05	43.702	0.009*	368.64	25.231	<0.001*	373.45	5.894	<0.001*
	T1	380.00	40.780		334.95	21.140		329.77	6.294	
33	T0	453.18	36.542	0.016*	420.86	41.881	0.034*	470.23	20.894	<0.001*
	T1	419.59	36.388		387.23	45.350		407.73	41.880	
Average	T0	420.9395	8.76745	<0.001*	398.7114	17.25982	<0.001*	418.5395	6.42481	<0.001*
	T1	389.7041	9.04710		362.6205	19.24404		369.3800	7.45151	

Wilcoxon signed-rank test, *denotes statistical significance. CuNiTi: Copper nickel-titanium, NiTi: Nickel-titanium

Table 4: Inter-group comparison of toothwise mean differences in root lengths from T0 to T1.

Tooth	Group	*n*	Mean	Standard deviation	Standard error	Mean rank	*P*-value
43	CuNiTi	22	0.372727	0.1162174	0.0247776	15.91	<0.001*
	SE NiTi	22	0.504545	0.1214095	0.0258846	30.00	
	Nitinol	22	0.836364	0.1940679	0.0413754	54.59	
42	CuNiTi	22	0.168182	0.1286796	0.0274346	12.95	<0.001*
	SE NiTi	22	0.472727	0.1386390	0.0295579	35.00	
	Nitinol	22	0.704545	0.1495303	0.0318800	52.55	
41	CuNiTi	22	0.254545	0.1654065	0.0352648	16.45	<0.001*
	SE NiTi	22	0.536364	0.1648822	0.0351530	42.95	
	Nitinol	22	0.500000	0.0925820	0.0197386	41.09	
31	CuNiTi	22	0.213636	0.2053927	0.0437899	20.57	<0.001*
	SE NiTi	22	0.531818	0.2476295	0.0527948	41.57	
	Nitinol	22	0.450000	0.2087377	0.0445030	38.36	
32	CuNiTi	22	0.218182	0.2084783	0.0444477	17.36	<0.001*
	SE NiTi	22	0.563636	0.0492366	0.0104973	39.59	
	Nitinol	22	0.554545	0.2132007	0.0454545	43.55	
33	CuNiTi	22	0.318182	0.0852803	0.0181818	12.77	<0.001*
	SE NiTi	22	0.581818	0.0732664	0.0156204	38.14	
	Nitinol	22	0.709091	0.1715728	0.0365794	49.59	

Kruskal–Wallis analysis of variance, $P \leq 0.05$ considered statistically significant, *denotes statistical significance. CuNiTi: Copper nickel-titanium, SE NiTi: Superelastic nickel-titanium

The results of this study reflected a statistically significant reduction in the average root length of the six mandibular anterior teeth at the post-alignment time point with nitinol, superelastic, and CuNiTi. A similar observation was reflected in the average root volume between the 2 time points in the three groups. The amount of resorption observed in our study with superelastic NiTi wires (0.53 mm) is close to the values reported by Jain *et al.* (0.59 mm).[5] However,

Table 5: Intergroup comparison of toothwise mean differences in root volumes from T0 to T1.

Tooth	Group	*n*	Mean	Standard deviation	Standard error	Mean rank	*P*-value
43	CuNiTi	22	35.82	11.379	2.426	21.20	<0.001*
	SE NiTi	22	46.23	9.375	1.999	33.39	
	Nitinol	22	53.14	3.091	0.659	45.91	
42	CuNiTi	22	26.36	8.732	1.862	14.64	<0.001*
	SE NiTi	22	31.59	24.071	5.132	35.18	
	Nitinol	22	43.82	8.633	1.841	50.68	
41	CuNiTi	22	39.09	14.145	3.016	29.50	0.047*
	SE NiTi	22	40.91	13.925	2.969	29.27	
	Nitinol	22	59.05	38.424	8.192	41.73	
31	CuNiTi	22	24.50	5.738	1.223	24.77	0.024*
	SE NiTi	22	30.50	9.733	2.075	35.73	
	Nitinol	22	32.77	10.000	2.132	40.00	
32	CuNiTi	22	28.05	12.423	2.649	20.86	<0.001*
	SE NiTi	22	33.68	11.378	2.426	31.77	
	Nitinol	22	43.68	2.169	0.462	47.86	
33	CuNiTi	22	33.59	16.279	3.471	26.86	<0.001*
	SE NiTi	22	33.64	8.307	1.771	24.23	
	Nitinol	22	62.50	37.261	7.944	49.41	

Kruskal–Wallis analysis of variance; $P \leq 0.05$ considered statistically significant; *denotes statistical significance. CuNiTi: Copper nickel-titanium, SE NiTi: Superelastic nickel-titanium

Table 6: Comparison of time span (in days) between the study groups.

Group	*n*	Mean	Standard deviation	Standard error	95% CI lower bound	95% CI upper bound	F-value	*P*-value
CuNiTi	22	105.50	7.190	1.533	102.31	108.69	15.42	<0.001*
Superelastic NiTi	22	112.14	7.803	1.664	108.68	115.60		
Nitinol	22	118.23	7.801	1.663	114.77	121.69		

One-way analysis of variance, *denotes statistical significance, CI: Confidence interval, CuNiTi: Copper nickel-titanium, NiTi: Nickel-titanium

the root resorption observed in our study with CuNiTi (0.25 mm) was significantly lower than that reported by Jain *et al*. (0.50 mm).[5] This difference could be due to variations in the manufacturer and batch differences. 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 established that notable differences exist from production lot to production lot of wires from the same manufacturer.[16]

Alzahawi *et al*.[14] reported significantly higher values than the root resorption values in the current study, which could be due to overestimation usually observed with periapical radiographs. The greater reduction in root length and volume observed in canines compared to central and lateral incisors may be attributed to the increased load at the apical area during distal tipping and uprighting movements. These findings highlight the importance of considering differential forces across the dental arch to optimize outcomes and minimize adverse effects during orthodontic treatment.

While the current study provided valuable insights, prior studies evaluating the efficacy of initial aligning archwires often faced limitations such as variations in bracket schemes, ligation techniques, extraction methods, and observation periods. To address these gaps, this study standardized these variables, ensuring a robust evaluation of the three types of NiTi wires.

In terms of alignment efficiency, CuNiTi wires outperformed superelastic NiTi and nitinol wires, requiring the shortest time to achieve alignment. This finding is consistent with the study by de Castro Serafim *et al*.[17] who also reported superior alignment with CuNiTi wires. The ability of CuNiTi wires to express their superelastic properties fully, even with smaller deflections, likely contributed to their efficiency in achieving alignment. This contrasts with findings by Abdelrahman *et al.*[2] and Pandis *et al.*,[18] where no significant differences in alignment efficiency were noted among different NiTi wires. These differences may stem from variations in study designs, including wire dimensions, irregularity indices, and observation periods. The authors in their study were not conclusive about the amount of irregularity, and the observation period was expanded to 6 weeks until the initial alignment was completed with a 0.014-inch arch wire. The authors reasoned that large deflections in the wire were required to express the super-elastic property, which was not fully expressed in their study.

Pandis *et al.*[18] reached a similar conclusion by comparing the efficiencies of CuNiTi and NiTi archwires. He reported that severe crowding (>5 mm on the irregularity index) showed a significantly higher probability of duration of crowding alleviation relative to dental arches with a score of <5 (138.5 vs. 113.1 days). The values reported in the current study were CuNiTi versus superelastic NiTi versus nitinol (105, 112, and 118 days). Pandis *et al.*[18] confined a 0.16 dimension wire during the entire period of 6 months observation, while the current study employed full dimensions rectangular wires in the three groups, achieving complete slot engagement, greater deflection, and higher superelasticity, resulting in increased alignment efficiency. The results of the present study are consistent with a clinical trial by phermsang-ngarm[19] who reported that heat-activated NiTi wires required less alignment time than super-elastic NiTi wires. However, studies by Nabbat and Yassir[13] Azizi *et al.*[20] Atik *et al.*[21] Aydin *et al.*[12] found that both superelastic NiTi and CuNiTi were equally effective in the aligning stage of orthodontic treatment. The above-mentioned studies had limitations that could hinder the complete expression of the properties of the respective NiTi wires, such as an irregularity index that requires non-extraction orthodontic treatment, smaller-dimension round wires, and a limited span of observation spanning around 6–12 weeks.

CONCLUSION

The following are the salient conclusions from the present study.

1. Root resorption of mandibular incisors after levelling was statistically different between the three groups of NiTi wires
2. Root resorption was minimal with CuNiTi and maximum with conventional nitinol wires
3. CuNiTi exhibited superior alignment efficiency over superelastic NiTi and conventional nitinol wires.

Clinical implications

This study supports the hypothesis that adding copper to NiTi wires reduces loading stress while maintaining high unloading stress, minimizing orthodontically induced inflammatory root resorption, and improving tooth movement efficiency. The lower deactivation forces and rapid tooth movement provided by CuNiTi allow for early engagement of thicker and rectangular wires, offering better torque and rotational control from the beginning of treatment.

In low-friction mechanics, thermal wires are preferable during the alignment phase due to their lower working forces and ability to express superelastic properties at lower deflections. They enable full-bracket engagement at treatment onset, reducing excessive force risks in cases of severe crowding. Their ability to produce consistent low forces over extended activation ranges minimizes the need for frequent reactivation.

In conventional straight-wire mechanics, superelastic NiTi wires are more suitable, as thermal wires may struggle to overcome ligature friction. Superelastic NiTi is ideal for moderate crowding or when arch form and torque control are required early in treatment. However, in cases of severe crowding or periodontal concerns, rectangular CuNiTi (35°C and 40°C) is recommended due to its controlled force delivery and superior torque control.

While statistically significant differences in alignment efficiency were observed among the three wire types, their clinical significance may be less pronounced, particularly given the higher cost of CuNiTi, which is twice that of superelastic NiTi.

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