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Alignment Efficiency of Superelastic and Heat-Activated Nickel–Titanium Archwires During Initial Orthodontic Alignment: A Randomized Clinical Trial

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Abstract

Background: Levelling and alignment constitute the initial and one of the most critical phases of fixed orthodontic treatment. Nickel–titanium (NiTi) archwires are routinely used during this stage because of their favourable biomechanical properties; however, the comparative clinical alignment efficiency of superelastic and heat-activated NiTi archwires remains uncertain.

Aim: To compare the clinical alignment efficiency of superelastic nickel–titanium (SENT) and heat-activated nickel–titanium (HANT) archwires during the initial alignment phase of fixed orthodontic treatment in patients with mild-to-moderate anterior crowding.

Methods: In this randomized clinical trial, orthodontic patients aged 11–25 years presenting with 3.0–6.9 mm of anterior segment crowding and requiring non-extraction fixed appliance therapy were randomly allocated (1:1) to either the HANT or SENT group. Both groups followed an identical archwire sequence (0.014-inch, 0.016-inch, and 0.018-inch NiTi), with each archwire maintained for four weeks. Anterior segment crowding was measured at baseline and at 4-week intervals over a 12-week period. Changes in alignment were analysed using repeated-measures analysis of variance (ANOVA), with statistical significance set at $P < 0.05$.

Results: Thirty-eight dental arches were randomized and included in the final analysis (19 arches per group). The mean participant age was 20.05 ± 5.14 years, and baseline demographic and clinical characteristics were comparable between groups ($P > 0.05$). Over the 12-week observation period, the mean reduction in anterior segment crowding was 3.90 mm in the HANT group and 3.46 mm in the SENT group. The between-group difference was not statistically significant (P = 0.809).

Conclusions: Heat-activated and Superelastic nickel–titanium archwires demonstrated comparable clinical efficiency for the alignment of mild-to-moderate anterior crowding during the initial phase of fixed orthodontic treatment.

ORIGINAL ARTICLE

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Introduction

Dental crowding is one of the most prevalent malocclusions encountered in orthodontic practice and arises from a discrepancy between tooth size and arch dimensions, resulting in irregular tooth alignment.[1] It is commonly classified as mild (0–3 mm), moderate (4–7 mm), or severe (>7 mm) according to the degree of space discrepancy.[2,3] Global prevalence estimates range from 16% to 59%, with anterior segment crowding representing one of the most frequent clinical presentations.[4] Nigerian studies similarly report a high prevalence of anterior crowding, particularly in the mandibular anterior region, highlighting its importance within the local orthodontic population.[1,5]

Levelling and alignment constitute the initial phase of fixed appliance therapy and establish the foundation for subsequent stages of orthodontic treatment.[6] [7,8] Efficient resolution of crowding during this stage facilitates progression through treatment while minimizing patient discomfort and reducing the risk of undesirable biological effects.[9,10] Consequently, initial aligning archwires are designed to deliver light, continuous forces that promote controlled tooth movement while preserving periodontal health.[7,8]

Nickel–titanium (NiTi) archwires have become the materials of choice during the alignment phase because of their low stiffness, high elasticity, and ability to produce relatively constant orthodontic forces over a wide range of activation.[11,12] Contemporary NiTi archwires are broadly categorized as conventional, superelastic, and heat-activated alloys.[11,13] Superelastic nickel–titanium (SENT) archwires undergo stress-induced phase transformation and generate relatively constant forces with high spring-back characteristics.[11] In contrast, heat-activated nickel–titanium (HANT) archwires exhibit thermally induced shape memory, becoming more flexible at lower temperatures and expressing orthodontic forces as they approach intraoral temperature.[11,14,15] These characteristics may facilitate archwire engagement in crowded dentitions while delivering lower force levels than superelastic wires.[16,17]

Although both archwire types are widely used during initial alignment, their comparative clinical performance remains uncertain.[18–20] Some randomized clinical trials have reported more rapid alignment with superelastic NiTi archwires, whereas others have found no significant differences between superelastic and heat-activated NiTi in the rate of crowding resolution.[21,22] Systematic reviews, including Cochrane reviews, have concluded that the available evidence is insufficient to establish the superiority of either archwire because of considerable heterogeneity in study design, including differences in bracket systems, ligation methods, extraction protocols, and outcome measures.[8,14,23–27]

The biological effects of these archwires have also attracted considerable interest.[28,29] Because superelastic NiTi archwires deliver relatively continuous forces and exhibit greater spring-back, they have been hypothesized to increase the risk of orthodontically induced inflammatory root resorption compared with heat-activated wires, which generate lighter and more intermittent force delivery.[19,30] However, current clinical evidence remains inconclusive, and few randomized trials have evaluated root resorption alongside alignment efficiency.[19,30]

Accordingly, this randomized clinical trial compared the alignment efficiency of superelastic and heat-activated nickel–titanium archwires during the first 12 weeks of fixed appliance therapy in patients with mild-to-moderate anterior segment crowding. To minimize sources of bias identified in previous investigations, treatment variables—including bracket prescription, slot dimension, ligation method, archwire sequence, and non-extraction treatment protocol—were standardized across both study groups.[31–34].

Methods

Study design

This single-centre, parallel-group randomized clinical trial employed a non-stratified randomization design with an equal allocation ratio (1:1). The trial was conducted at the Orthodontic Unit, Department of Child Dental Health, Lagos University Teaching Hospital, Lagos, Nigeria. Ethical approval was obtained from the Lagos University Teaching Hospital Health Research Ethics Committee (ADM/DCST/HREC/APP/5061), and the trial was registered with the Pan African Clinical Trials Registry (PACTR202307594421954).

Participants

Patients aged 11–25 years who required comprehensive fixed appliance therapy were screened for eligibility. Participants were included if they presented with mild-to-moderate anterior segment crowding (Little's Irregularity Index, 3.0–6.9 mm), had fully erupted permanent anterior teeth in the study arch, required non-extraction treatment, and provided written informed consent or assent.

Patients were excluded if they had crowding <3.0

mm or >6.9 mm, anterior spacing, craniofacial anomalies, impacted teeth requiring surgical exposure, lingually or palatally displaced teeth that precluded bracket placement at bonding, previous orthodontic treatment, planned extraction therapy, or were taking medications known to influence orthodontic tooth movement, including bisphosphonates and non-steroidal anti-inflammatory drugs.

Sample size

Sample size was calculated for a two-arm parallel randomized clinical trial with normally distributed continuous outcomes, assuming 90% statistical power and a two-sided significance level of 5%. After allowing for possible attrition, a minimum sample of 19 arches per group (38 arches in total) was required. The calculated sample size was consistent with those reported in comparable randomized clinical trials.[20,28,31,35,36] Participants contributed one or both arches, provided they satisfied the eligibility criteria.

Randomization

Participants were recruited consecutively after meeting the eligibility criteria and providing written informed consent. Eligible participants were randomly assigned to either the superelastic nickel–titanium (SENT) or heat-activated nickel–titanium (HANT) group using simple randomization with a 1:1 allocation ratio. The allocation sequence consisted of 38 sequentially prepared, opaque, sequentially numbered and sealed envelopes containing equal numbers of treatment assignments (paper slips written SENT or HANT). A study-independent individual who was not involved in treatment delivery or outcome assessment prepared and administered the envelopes. Following enrolment, each participant selected one sealed envelope, and the treatment assignment contained therein determined the archwire group. The allocation remained concealed until the envelope was opened immediately before initiation of treatment.

Orthodontic intervention

Following prophylaxis with oil-free pumice, enamel surfaces were etched with 37% phosphoric acid for 30 seconds before bonding pre-adjusted edgewise Roth prescription 0.022-inch brackets (Equilibrium® 2; Dentaurum, Ispringen, Germany). Brackets were bonded using Ortho Solo™ primer and Enlight™ orthodontic adhesive (Ormco Corporation, Glendora, CA, USA). Bracket positioning was standardized using a bracket-positioning gauge.

Participants assigned to the SENT group received Rematitan Lite nickel–titanium archwires (Dentaurum, Germany), while those in the HANT group received Tensic thermo-active nickel–titanium archwires (Dentaurum, Germany). Both groups followed an identical archwire sequence of 0.014-inch, 0.016-inch, and 0.018-inch archwires, with each archwire maintained for four weeks.

Participants were reviewed at 4-week intervals over a 12-week observation period. At each visit, the subsequent archwire in the sequence was inserted, and alginate impressions were obtained to produce dental stone study casts. Casts obtained at baseline, 4, 8, and 12 weeks were designated T0, T1, T2, and T3, respectively.

Outcome measures

Alignment efficiency, assessed as the reduction in anterior segment crowding measured on serial study casts using Little's Irregularity Index. Measurements were obtained at baseline and after 4, 8, and 12 weeks of treatment.

Statistical analysis

Data were analysed using IBM SPSS Statistics (Version 26.0; IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro–Wilk test. Continuous variables were summarized as mean ± standard deviation, whereas categorical variables were presented as frequencies and percentages.

Baseline differences between treatment groups were evaluated using the independent-samples *t*-test for continuous variables and Fisher's exact test for categorical variables. Changes in anterior segment crowding and root length between groups were compared using independent-samples *t*-tests. Repeated-measures analysis of variance (ANOVA) was used to evaluate changes in anterior segment crowding over time. Statistical significance was set at $P < 0.05$.

Measurement reliability

Intra-examiner reproducibility was assessed by repeating measurements on five study casts and five CBCT images after a one-week interval. Measurement error was evaluated using Dahlberg's formula, which yielded a value of 0.79.

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RECRUITMENT PROTOCOL

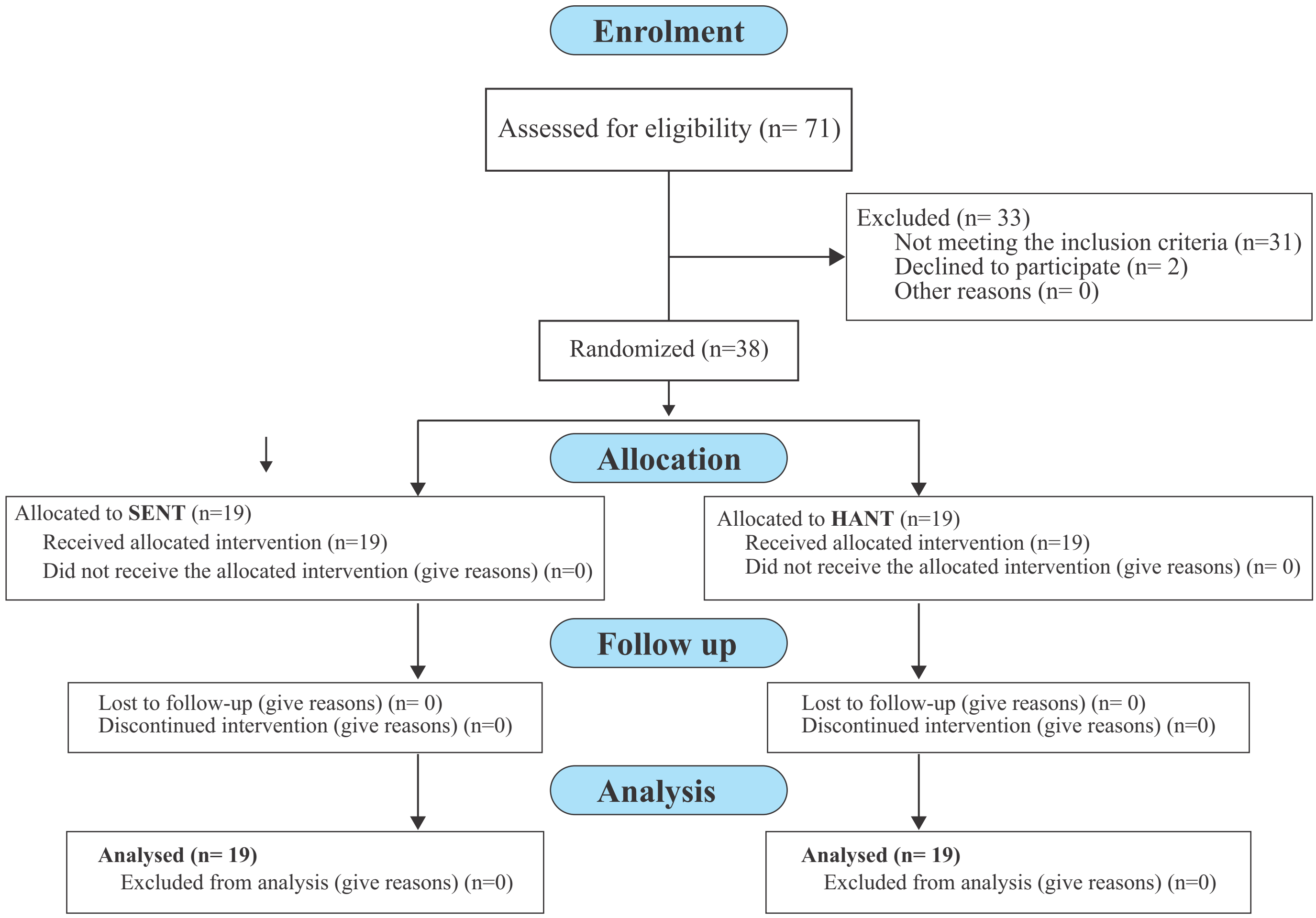

Figure 1: Recruitment Protocol

Results

A total of 38 arches were enrolled and included in the analysis. The study population comprised 14 females (66.7%) and 7 males (33.3%), with a mean age of 20.05 ± 5.14 years (range, 11–25 years). The mean age was 19.0 ± 5.0 years in the SENT group and 21.2 ± 5.3 years in the HANT group, with no statistically significant difference between groups ($P = 0.340$).

Table 1: Socio-demographic characteristics of participants from which thirty-eight arches were recruited.

	SENT N (%)	HANT N (%)	Total	Fisher exact test	*p*-value
Age (Mean ± SD)	19.00 ± 5.0	21.20 ± 5.3			
Gender					
Male	3 (27.3)	4 (40.0)	7 (33.3)	0.978*	0.340
Female	8 (72.7)	6 (60.0)	14 (66.7)	0.382	0.537

Distribution of arches and severity of crowding between the archwire groups.

A total of 38 dental arches were randomized, with 19 arches allocated to each treatment group. Both the SENT and HANT groups comprised nine maxillary (47.4%) and ten mandibular (52.6%) arches (Figure 1).

At baseline, the majority of arches exhibited moderate anterior segment crowding according to Little's Irregularity Index. In the SENT group, 18 arches (94.7%) presented with moderate crowding and one arch (5.3%) with mild crowding. In the HANT group, 12 arches (63.2%) had moderate crowding, while seven arches (36.8%) exhibited mild crowding. The baseline distribution of crowding severity was comparable between the two treatment groups, with no statistically significant difference ($P = 0.616$).

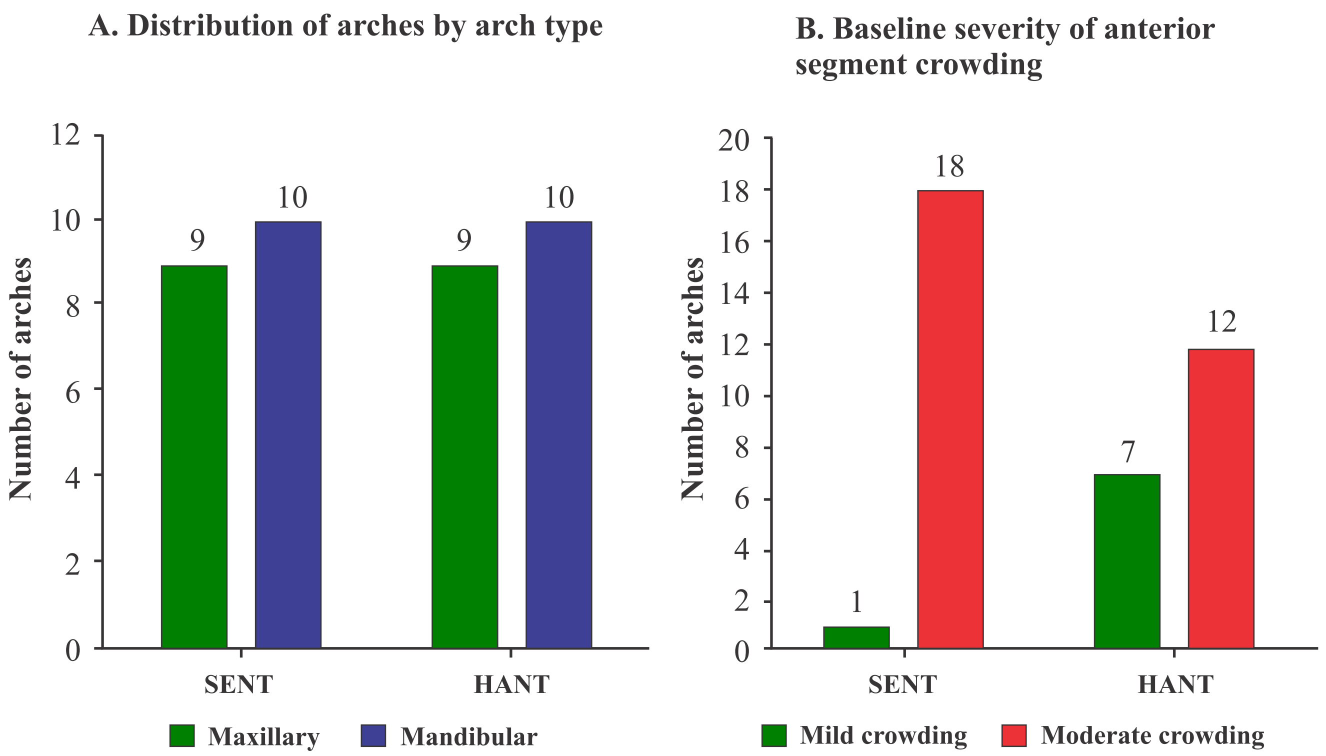

Figure 2: Distribution of maxillary and mandibular arches (Panel A) and baseline severity of anterior segment crowding according to Little's irregularity Index (Panel B) in the superelastic nickel-titanium (SENT) and heat-activated nickel-titanium (HANT) groups

Changes in anterior segment crowding within treatment groups

In both treatment groups, mean anterior segment crowding (ASC) decreased progressively throughout the 12-week observation period (Table 2). In the SENT group, the reduction in ASC was observed in both the maxillary and mandibular arches at each review interval, with mean residual crowding of <1.0 mm in both arches by week 12. Although the maxillary arch demonstrated consistently lower mean ASC than the mandibular arch throughout treatment, the differences were not statistically significant ($P > 0.05$).

Similarly, the HANT group exhibited a progressive reduction in ASC in both arches over time. By week 12, mean residual crowding was 1.18 ± 0.30 mm in the maxillary arch and 0.77 ± 0.20 mm in the mandibular arch. While the mandibular arch consistently demonstrated lower mean ASC than the maxillary arch, the between-arch differences were not statistically significant ($P > 0.05$) (Table 2).

Table 2: Comparison of anterior segment crowding at various review times, within each archwire group.

	Maxillary arch Mean±SD (mm)	Mandibular arch Mean±SD (mm)	t-value	*p*-value
SENT				
Baseline	4.26 ± 0.6	4.89 ± 1.0	-1.616	0.124
4 weeks review period	2.76 ± 0.7	3.15 ± 1.3	-0.801	0.434
8 weeks review period	1.45 ± 0.5	1.9 ± 0.7	-1.328	0.202
12 weeks review period	0.49 ± 0.1	0.89 ± 0.5	-1.313	0.207
HANT				
Baseline	4.62 ± 0.6	4.25 ± 0.8	1.080	0.295
4 weeks review period	2.80 ± 0.6	2.59 ± 0.7	0.655	0.522
8 weeks review period	1.97 ± 0.7	1.55 ± 0.5	1.419	0.174
12 weeks review period	1.18 ± 0.3	0.77 ± 0.2	1.647	0.118

Comparison of the Anterior Segment crowding between the archwire groups at the review times.

Mean anterior segment crowding (ASC) decreased progressively in both treatment groups throughout the 12-week study period (Table 3). At 4 weeks, mean ASC was slightly greater in the SENT group than in the HANT group (2.96 ± 0.60 mm vs. 2.69 ± 0.70 mm); however, the difference was not statistically significant ($P = 0.352$). By 8 weeks, mean ASC was comparable between the SENT and HANT groups (1.72 ± 0.40 mm vs. 1.75 ± 0.50 mm; $P = 0.897$). At the end of the 12-week observation period, residual crowding remained lower in the SENT group (0.70 ± 0.20 mm) than in the HANT group (0.96 ± 0.30 mm), although the between-group difference did not reach statistical significance ($P = 0.202$).

Repeated-measures analysis of variance demonstrated a significant reduction in anterior segment crowding over time within both treatment groups ($P < 0.001$). However, no statistically significant differences in alignment efficiency were observed between the SENT and HANT archwires at any assessment interval (Tables 3 and 6).gnificant (p < 0.001). This is shown in Table VI.

Table 3: Comparison of the anterior segment crowding between the archwire groups at the review times.

	SENT (n=19) Mean±SD (mm)	HANT (n=19) Mean±SD (mm)	t-value	*p*-value
Baseline	4.59 ± 0.9	4.43 ± 0.8	0.609	0.546
4 weeks review period	2.96 ± 0.6	2.69 ± 0.7	0.944	0.352
8 weeks review period	1.72 ± 0.4	1.75 ± 0.5	0.130	0.897
12 weeks review period	0.70 ± 0.2	0.96 ± 0.3	0.130	0.202
F-value	**10.047**	**8.722**		
p-value	**<0.001***	**<0.001***		

Reduction in anterior segment crowding at different treatment intervals

The reduction in anterior segment crowding (ASC) was evaluated over three treatment intervals: Δ1 (baseline–4 weeks), Δ2 (4–8 weeks), and Δ3 (8–12 weeks) (Table 4). During Δ1, the HANT group demonstrated a slightly greater mean reduction in ASC than the SENT group (1.74 ± 0.40 mm vs. 1.63 ± 0.50 mm), although the difference was not statistically significant (P = 0.499).

In contrast, the SENT group exhibited greater mean reductions in ASC during both Δ2 (1.25 ± 0.40 mm vs. 0.94 ± 0.30 mm; P = 0.073) and Δ3 (1.02 ± 0.40 mm vs. 0.78 ± 0.20 mm; P = 0.091). Similar trends were observed in both the maxillary and mandibular arches. However, none of the between-group differences reached statistical significance. significant. This is shown in Table 4.

Table 4: Comparison of the anterior segment crowding between the archwire groups at the review times.

	SENT (n=19) Mean±SD (mm)	HANT (n=19) Mean±SD (mm)	t-value	*p*-value
Δ1	1.63 ± 0.5	1.74 ± 0.4	0.683	0.499
Δ2	1.25 ± 0.4	0.94 ± 0.3	1.846	0.073
Δ3	1.0 ± 0.4	0.78 ± 0.2	1.738	0.091
	Maxillary arch			
Δ1	1.50 ± 0.4	1.82 ± 0.6	1.351	0.195
Δ2	1.30 ± 0.5	0.83 ± 0.5	1.946	0.069
Δ3	0.97 ± 0.3	0.79 ± 0.2	1.473	0.160
	Mandibular arch			
Δ1	1.74 ± 0.6	1.66 ± 0.3	0.359	0.724
Δ2	1.20 ± 0.7	1.04 ± 0.3	0.681	0.504
Δ3	1.06 ± 0.7	0.78 ± 0.3	1.190	0.249

Δ1 ⊿1 = Baseline - 4 weeks Δ2 , ⊿2 = 4 weeks - 8 weeks , ⊿3 and Δ3 = 8 weeks - 12 weeks.

Discussion

The present randomized clinical trial compared the alignment efficiency of superelastic nickel–titanium (SENT) and heat-activated nickel–titanium (HANT) archwires during the initial 12 weeks of fixed appliance therapy in patients with mild-to-moderate anterior segment crowding. Both archwire systems produced significant reductions in anterior segment crowding over the study period. Although HANT demonstrated a marginally greater reduction in crowding during the first four weeks of treatment, SENT achieved numerically greater reductions during the subsequent treatment intervals and exhibited lower residual crowding at 12 weeks. However, none of the between-group differences reached statistical significance, indicating that both archwire systems demonstrated comparable clinical alignment efficiency.

The comparable baseline characteristics observed between the two treatment groups suggest that the randomization procedure was successful in minimizing selection bias. There were no statistically significant differences in age, sex distribution, malocclusion characteristics, or baseline anterior segment crowding, thereby reducing the likelihood that these variables influenced the treatment outcomes. The inclusion of both maxillary and mandibular arches, together with standardized bracket prescription, slot dimension, ligation method, archwire sequence, and a uniform non-extraction treatment protocol, further strengthened the internal validity of the study by minimizing potential confounding factors identified in previous clinical trials.

Progressive reduction in anterior segment crowding was observed in both treatment groups throughout the 12-week observation period, reflecting the effectiveness of nickel–titanium archwires during the initial alignment phase. This finding is consistent with the well-established biomechanical properties of NiTi alloys, which provide relatively light and continuous orthodontic forces capable of producing efficient tooth movement while minimizing adverse effects on the supporting periodontal tissues.[8,11,21,30,34,36–40]

An interesting observation in the present study was the difference in the pattern of alignment over time. During the first four weeks of treatment, the HANT group demonstrated a slightly greater reduction in anterior segment crowding than the SENT group, although this difference was not statistically significant. This early numerical advantage may reflect the greater flexibility of heat-activated NiTi archwires at lower temperatures, allowing easier engagement of displaced teeth during initial archwire placement.[11,41,42] Their thermally activated phase transformation enables the delivery of relatively light forces as intraoral temperature increases, which may facilitate early alignment in crowded dentitions.[11,15,43,44]

In contrast, SENT archwires demonstrated numerically greater reductions in anterior segment crowding during the 4–8 week and 8–12 week treatment intervals. Although these differences also failed to reach statistical significance, they may reflect the sustained force delivery associated with the superelastic properties of SENT archwires.[11,14,44,45]

As tooth alignment progresses and archwire deflection decreases, superelastic alloys may be better able to maintain relatively constant force levels because of their lower hysteresis and greater spring-back characteristics.[44–46] Nevertheless, these observations were not statistically significant, the differences may be the result of biomechanics.

Despite these differences in alignment patterns, both archwire systems produced similar overall reductions in anterior segment crowding after 12 weeks. Repeated-measures analysis of variance demonstrated significant improvement in alignment over time within each treatment group, whereas no significant differences were observed between groups at any assessment interval. These findings suggest that, under standardized clinical conditions, the choice between superelastic and heat-activated nickel–titanium archwires has little influence on the overall efficiency of initial alignment in patients with mild-to-moderate crowding.[7,14,23,26,27,47]

The findings of the present study are consistent with several randomized clinical trials that have reported comparable alignment efficiency between superelastic and heat-activated NiTi archwires. Studies by Nabbat et al.[31], Ong et al.[18], Abdelrahman et al.[48], Pandis et al.[39], Mahmoud et al. [30], and Cioffi et al.[49] similarly demonstrated no statistically significant differences in the rate of alignment despite small numerical differences favouring one archwire system over the other. Collectively, these findings support the conclusions of previous systematic reviews and Cochrane reviews, which reported insufficient high-quality evidence to establish the superiority of either superelastic or heat-activated NiTi archwires during the alignment phase of orthodontic treatment.[7,14,23,26,27,47]

In contrast, Serafim et al.[50] reported significantly greater alignment with heat-activated NiTi archwires. However, direct comparison with the present findings should be interpreted with caution because that study compared heat-activated NiTi with conventional NiTi rather than with superelastic NiTi. Conventional NiTi archwires possess different mechanical characteristics and generally exhibit lower superelastic behaviour than modern superelastic alloys, making comparisons between studies inherently difficult.[11,14,36,40,51,52]

Assessment of the maxillary and mandibular arches demonstrated progressive reduction in anterior segment crowding irrespective of arch location. Although numerical differences were observed between arches within each treatment group, these differences were not statistically significant. Variations in baseline crowding and differences in inter-bracket span between the maxillary and mandibular arches may partly explain these observations, but their clinical impact appears minimal under the treatment protocol employed in the present study.

From a clinical perspective, the findings suggest that both superelastic and heat-activated nickel–titanium archwires can be expected to provide comparable alignment efficiency during the initial phase of fixed appliance therapy. Consequently, archwire selection may reasonably be based on other clinically relevant considerations, including ease of ligation, patient comfort, cost, operator preference, and biological effects such as orthodontically induced root resorption, rather than alignment efficiency alone.

Overall, the findings of this study indicate that both superelastic and heat-activated nickel–titanium archwires provide effective and clinically comparable alignment of mild-to-moderate anterior crowding during the initial stage of fixed appliance therapy. Although each archwire exhibited a slightly different pattern of alignment over time, these differences were not statistically significant and are unlikely to be clinically meaningful.

LIMITATIONS

First, it was conducted at a single tertiary referral centre, which may limit the generalizability of the findings to other clinical settings and populations. Second, the 12-week follow-up period restricted the evaluation to the initial alignment phase of orthodontic treatment. Although adequate for evaluating early alignment, longer observation periods may be required to determine whether differences emerge during subsequent treatment stages. Finally, because some participants contributed both maxillary and mandibular arches, complete statistical independence of observations could not be assumed. Future multicentre randomized clinical trials with larger sample sizes, longer follow-up periods, and statistical methods that account for clustering of arches within participants are recommended to provide more robust evidence regarding the comparative clinical performance of these archwire systems.

CONCLUSION

Both superelastic nickel–titanium (SENT) and heat-activated nickel–titanium (HANT) archwires produced significant reductions in anterior segment crowding during the initial 12 weeks of fixed appliance therapy. No statistically significant differences in alignment efficiency were observed between the two archwire systems at any assessment interval. The choice between SENT and HANT archwires should therefore be guided by clinical considerations such as ease of handling, patient comfort, operator preference, and cost, rather than expectations of superior alignment efficiency.

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