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Influence of crowding severity on alignment efficiency during initial orthodontic treatment with different nickel-titanium archwires in mandibular arch

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Abstract:
The efficiency of initial orthodontic alignment may vary among different nickel-titanium archwire systems, with comparative clinical evidence needed to guide archwire selection. Therefore, it is of interest to compare the conventional, superelastic and thermo elastic nickel-titanium archwires during the initial phase of fixed orthodontic treatment, with dental alignment assessed using little's irregularity index over 4 months. All three archwire systems produced significant improvement in alignment, while Superelastic and Thermo elastic archwires showed slightly faster alignment than conventional archwires, although the differences were not statistically significant. All three nickel-titanium archwire systems showed comparable clinical effectiveness for initial orthodontic alignment. Thus, data shows the clinical equivalence of conventional, superelastic and thermo elastic nickel-titanium archwires during the initial alignment phase of orthodontic treatment.

Keywords: Alignment, nickel-titanium (NiTi) archwire, little's irregularity index

Background:
Crowding is a common malocclusion, which needs orthodontic correction. The first step of therapy is alignment and leveling which are also the key steps to achieve appropriate occlusion and tooth location. The nickel-titanium archwires are commonly employed because of their good mechanical properties **[1, 2].**Crowding, rotations and other dental anomalies are extensively treated by orthodontic treatment. It is done with fixed appliances including of brackets and archwires. Initial archwires are critical in reducing crowding and directing tooth mobility. Nickel-titanium (NiTi) archwires are widely used due to their flexibility, elasticity, spring back and capacity to exert light continuous stresses. These qualities allow effective tooth movement with little tissue damage and improved clinical performance throughout the alignment phase **[2, 3].** Multistranded stainless steel wires were the first to be used for orthodontic alignment but have been mainly supplanted by nickel titanium (NiTi) archwires due to their greater elasticity and robustness. With the evolution of NiTi technology, superelastic and heat-activated types have been developed. They apply light and continuous stresses to achieve better tooth movement. The clinical efficacy of copper-containing and thermo active NiTi archwires is further enhanced by providing temperature-responsive forces that may optimize tissue response in the course of orthodontic alignment **[4, 5].** In an effort to improve the transformation characteristics of typical NiTi alloys, copper nickel-titanium (CuNiTi) archwires were introduced **[6].** These wires are available in different transition temperatures and provide a controlled, temperature dependant force delivery. Copper improves phase stability which results in a more stable force expression, even loading and better biomechanical efficiency. Hence, during the early phase of orthodontic tooth movement CuNiTi arch wires are more predictable and effective **[7].** Therefore, it is of interest to evaluate the influence of mandibular anterior crowding severity on the alignment efficiency of conventional, superelastic and thermo elastic nickel-titanium (NiTi) archwires during the initial phase of fixed orthodontic treatment.

Materials and Methods:
This prospective clinical study was conducted at the Department of Orthodontics and Dentofacial Orthopaedics, Government Dental College, Raipur. The study was approved by the Institutional Scientific and Ethical Committee, IEC Proposal No. 5261/GDC/Institutional Ethics Committee/2024. All procedures performed were in accordance with ethical standards. Written informed permission was acquired from all subjects before enrollment. The study comprised 48 individuals in the age group of 15-25 years undergoing permanent orthodontic treatment for anterior crowding in mandibular arches. Patients with Angle's Class I or Class II malocclusion, with or without extraction treatment regimens and with a healthy periodontal and systemic state were included. Previous orthodontic treatment, anterior spacing, extraction of lower incisors, poor oral hygiene, or major medical disorders were exclusion criteria for the study. The sample size estimation was done using G*Power software based on previously published data. The minimum number of subjects in each group was 16 and the total sample size was 48 participants. Subjects were selected by stratified random sampling and grouped based on severity of anterior crowding using Little's Irregularity Index. Three grouping crowds were constructed: mild crowding (n = 16), moderate crowding (n = 16) and severe crowding (n = 16). Patients were randomized into three crowding categories and assigned to receive one of three 0.014-inch nickel-titanium archwires: Thermo elastic (heat-activated) NiTi, superelastic NiTi, or standard NiTi. Allocation was concealed by the use of sealed opaque envelopes. All patients were bonded with 0.022-in MBT prescription brackets. Alginate impressions of the mandibular arch were taken before the therapy (T0) and then at monthly intervals for four months (T1–T4). Study casts were created at each time point and the alignment efficiency was evaluated with the help of Little's

Irregularity Index measured with the help of a digital vernier caliper. The degree of crowding was defined by the difference between the available arch length and the needed arch length. The required arch length was calculated by adding the mesiodistal widths of the incisors and canines and the available arch length was determined as the total distance from the mesial contact point of the central incisor to the distal contact point of the canine on either side of the arch. Rate of alignment was assessed by reduction of irregularity scores over time. During the alignment phase, the archwire was completely engaged and fastened using elastomeric modules in a figure-of-eight configuration at monthly follow-up appointments to guarantee full wire engagement throughout treatment. The collected data were coded and analyzed using SPSS software. Descriptive statistics were expressed as mean ± standard deviation (SD) and statistical significance was set at $p < 0.05$. Patients were categorized into mild, moderate and a severe crowding group based on little's Irregularity Index and randomly assigned to conventional, superelastic, or Thermo elastic NiTi archwire groups. One-way ANOVA was used to compare baseline characteristics and alignment efficiency at monthly intervals (T0–T4). Tukey's honestly significant difference (HSD) post hoc test was applied for pairwise comparisons when significant differences were identified.

Results:

Table 1 summarizes the influence of crowding severity on alignment efficiency during orthodontic treatment with conventional, superelastic and thermo elastic nickel-titanium (NiTi) archwires in the mandibular arch. Patients were stratified into mild, moderate and severe crowding groups to evaluate the effect of initial crowding severity on treatment outcomes. Alignment efficiency was assessed using Little's Irregularity Index over a four-month observation period. In the mild crowding group, all three archwire systems produced rapid and complete alignment within the early stages of treatment. Baseline irregularity scores were comparable among the groups and no statistically significant differences in alignment efficiency were observed at any evaluation interval, indicating similar clinical performance. In the moderate crowding group, all archwire systems demonstrated a progressive reduction in irregularity scores. However, superelastic and thermo elastic NiTi archwires achieved significantly greater alignment efficiency than conventional NiTi during the second month (ANOVA, $p = 0.007$). Post hoc analysis showed significantly slower alignment with conventional NiTi, whereas no significant difference was observed between the superelastic and thermo elastic archwires. Despite these interim differences, complete alignment was achieved in all groups by the fourth month. In the severe crowding group, the influence of archwire type became more pronounced. Thermo elastic and superelastic NiTi archwires consistently demonstrated faster alignment than conventional NiTi, with statistically significant differences observed at the third ($p = 0.038$) and fourth ($p = 0.003$) months. Tukey's post hoc analysis confirmed superior alignment with thermo elastic and superelastic NiTi compared with conventional NiTi, while no significant difference was detected between the two advanced archwire systems. Although all archwires effectively reduced crowding over time, residual irregularity remained greatest in the conventional NiTi group, particularly in patients with severe mandibular crowding.

Table 1: Influence of crowding severity on alignment efficiency during orthodontic treatment with different niti archwires (mandibular arch)

Crowding Severity	Alignment Efficiency	Conventional NiTi	Superelastic NiTi	Thermo elastic NiTi	Significant Difference
Mild	Complete alignment achieved by T2–T3 in all groups	Slowest initial alignment	Faster than conventional	Comparable to superelastic	No significant intergroup difference at any time point (T0: p=0.269, T1: p=0.149, T2: p=0.465)
Moderate	Progressive reduction in Little's Irregularity Index in all groups	Highest residual irregularity at T2 (1.44 ± 0.37)	Greatest reduction at T2 (0.38 ± 0.60)	Intermediate reduction (1.06 ± 0.33)	Significant difference at T2 only (ANOVA p=0.007); Tukey test showed Conventional vs Superelastic significant (Mean difference=1.06, p=0.006).
Severe	Continuous improvement throughout treatment	Slowest alignment with greatest residual irregularity at T4 (1.66 ± 0.41)	Faster alignment (0.50 ± 0.80 at T4)	Fastest alignment (0.05 ± 0.10 at T4)	Significant differences at T3 (p=0.038) and T4 (p=0.003). Tukey test: Conventional vs Thermo elastic significant at T3 (p=0.039); Conventional vs Superelastic (p=0.014) and Conventional vs Thermo elastic (p=0.003) at T4.

Abbreviations: LII = Little's Irregularity Index; T0 = Baseline; T1 = 1 month; T2 = 2 months; T3 = 3 months; T4 = 4 months.

Discussion:

The present study assessed the effect of severity of mandibular anterior crowding on the efficacy of alignment in the first 4 months of orthodontic treatment using conventional, superelastic and thermo elastic nickel-titanium (NiTi) archwires. Results revealed that all three systems of archwire were successful in reducing crowding, although superelastic and thermo elastic archwires had more efficiency of alignment especially in moderate and severe crowding. All three archwire methods provided rapid and complete alignment in patients with minor crowding without significant intergroup differences. The results indicate that the biomechanical advantages of the newer NiTi alloys have limited clinical effect when the amount of crowding is small. Similar results were reported by Amaya González *et al.* **[8]** showing comparable alignment efficiency between heat-activated and superelastic NiTi archwires in the early phases of orthodontic treatment. The distinctions among the archwire systems became increasingly apparent as the crowding severity rose. The superelastic and the thermo elastic NiTi wires were much faster in alignment than the normal NiTi wire in the moderate crowding group. These results are in agreement with the revised Cochrane systematic review by Liu *et al.* **[9]**, who found that NiTi archwires are effective in first alignment due to their advantageous biomechanical features.

Similarly, a comprehensive review and meta-analysis recently conducted by Bardideh *et al.* **[10]**, showed that heat activated NiTi archwires may have a better alignment efficiency compared to ordinary NiTi. The most significant differences were noticed in severe crowding, where the thermo elastic and superelastic NiTi archwires always resulted in faster alignment than the ordinary NiTi. Gonuguntla *et al.* **[11]** and Verghese *et al.* **[12]** proved that improved NiTi archwires can be used to align efficiently without increasing root resorption, which indicates their safety for clinical use. Tahamtan *et al.* **[13]** have showed that contemporary thermally activated NiTi alloys provide more efficient force delivery and better clinical performance during the alignment phase. Similar findings were also reported by Noori *et al.* **[14]** and they highlighted the necessity of optimal force systems for effective orthodontic tooth movement. The good performance of thermo elastic and superelastic NiTi archwires can be explained by their shape memory properties, superelasticity and the capability to provide light continuous forces in a wide range of activation. Azizi *et al.* **[15]** have highlighted the biological benefits of applying regulated orthodontic force and Elhanouty *et al.* **[16]** reported the faster alignment with improved arch wire sequence without any increase in undesirable effects such as root resorption. Moreover, Wichelhaus *et al.* **[17]** showed that the current developments in NiTi alloy metallurgy have led to an improvement of consistency of force and mechanical behavior, contributing to the better clinical efficiency. There are certain limitations of the present investigation. The limitations of the present study were; the limited sample size and the observation duration of 4 months which was merely the early stage of orthodontic therapy. Hence, the long-term clinical performance of different NiTi archwire systems could not be evaluated. Further studies with larger sample sizes, longer duration of follow-up and multi-center design are required to confirm these results and to evaluate the consequences of long-term therapy. Clinically all three NiTi archwire systems were effective in relieving crowding of mandibular anterior teeth. Nevertheless, superelastic and thermo elastic NiTi archwires presented faster alignment in moderate and severe crowding, which suggests that these archwires could be preferred when a superior efficiency of treatment is desired. They can be used to shorten the initial phase of alignment while still permitting safe and efficient tooth movement.

Conclusion:

All three types of nickel-titanium (NiTi) archwires showed effective correction of dental crowding during the initial alignment phase of orthodontic treatment. Superelastic and thermoelastic NiTi archwires achieved faster alignment, particularly in patients with moderate to severe crowding, owing to their favourable force delivery characteristics. In contrast, conventional NiTi archwires showed comparable effectiveness in mild crowding, suggesting that they remain a suitable option for cases requiring less extensive initial alignment.

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