Original Article

Efficiency, behavior, and clinical properties of superelastic NiTi versus multistranded stainless steel wires
A prospective clinical trial

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ABSTRACT

Objective: To investigate efficiency, behavior, and properties of superelastic NiTi vs multistranded stainless steel wires in Begg and preadjusted edgewise appliance (PEA) under moderate to severe crowding conditions.

Material and Methods: Ninety-six participants (48 male, 48 female), aged 12–18 years old (mean age $= 15.2 \pm 1.95$), with moderate (≤ 6 mm; mean $= 5.3 \pm 0.48$) to severe (> 6 mm; mean $= 7.9 \pm 0.66$) initial crowding were distributed into four groups: superelastic NiTi PEA (n = 24), superelastic NiTi Begg (n = 24), multistranded (coaxial) stainless steel PEA (n = 25), and multistranded (coaxial) stainless steel Begg (n=23). In this study, 0.16-inch superelastic (austenitic active) NiTi and 0.175-inch multistranded (six stranded, coaxial) stainless steel wires were used in a 0.022-inch slot (Roth prescription) PEA and Begg appliance with a follow-up of six weeks.

Results: Analysis of variance revealed no significant difference in reduction of crowding between superelastic NiTi PEA and multistranded (coaxial) stainless steel PEA groups, but reduction in crowding was significantly greater in the superelastic NiTi Begg group compared with the multistranded (coaxial) stainless steel Begg group with $F(3, 44) = 8.896$, $P < .001$, and effect size (ω) 0.57 in moderate crowding and $F(3, 44) = 122.341$, $P < .001$, and effect size (ω) 0.93 in severe crowding. Linear regression demonstrated significant ($P < .05$) positive correlation between amount of initial crowding and reduction in crowding in all groups except the multistranded (coaxial) stainless steel Begg group, wherein a negative correlation did exist.

Conclusion: Superelastic NiTi performed significantly better than multistranded (coaxial) stainless steel wire in the Begg appliance. However, in PEA, there was no significant difference. (*Angle Orthod.* 2012;82:915–921.)

KEY WORDS: PEA; Begg appliance; Superelastic NiTi; Multistranded (coaxial) stainless steel; Reduction in crowding

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INTRODUCTION

Most effective, efficient, and physiological tooth movement during the initial leveling and aligning phase of treatment requires forces generated by orthodontic appliance to be low, continuous, and within physiologic limits.[1–6] Therefore, the ideal initial archwire should be highly flexible and should exhibit a low load deflection rate, minimal plastic deformations, and excellent spring-back properties.[7] Multistranded stainless steel and nickel titanium alloys seem to be the closest archwire materials fulfilling these requirements.[8–11]

Though nickel titanium (NiTi) alloy–based wires are most commonly used during the leveling and aligning phase of treatment,[12] multistranded wires are proposed as an alternative to these wires based on classic mechanics theory (Strength = Stiffness × Range),[13] and over the decades, it has proved to be equally efficient as NiTi alloy–based wires.[14–16]

Though NiTi archwires have wide acceptance in orthodontics because of their low load-deflection ratio and better control of force magnitude, many authors[17,18] have expressed the need for clinical performance evaluation of these wires because their properties have not been assessed in clinical studies to the same extent as have their mechanical properties in the laboratory setup. Recently, Pandis et al.[19] studied copper (Cu) NiTi vs NiTi for the alleviation of mandibular crowding and concluded that the newest member of the NiTi family, that is, Cu NiTi, was not superior to NiTi in clinical situations. This study highlights the need for clinical evaluation of newer wires before considering them to be superior to more conventional wires. Often, under clinical situations, superelastic wires show no superelastic properties or advantage over non-superelastic NiTi wires because of the exceedingly high force level at the plateau, and that is not present in all clinical conditions.[12,14,20–22]

Studies comparing superelastic (austenitic-active) NiTi and multistranded stainless steel in preadjusted edgewise appliances (PEAs) found no differences in efficiency,[23,24] but no clinical study has evaluated the effect of brackets (eg, PEA vs Begg) on the behavior of these initial aligning wires. Hemingway et al.[25] studied the influence of bracket type on force delivery and concluded that several factors of the archwire/bracket combination affect force levels.

Begg appliances have some fundamental biomechanical differences from PEA (eg, interbracket distance due to difference in bracket width, one-point vs two-point bracket-archwire contact, method of tying the wire into slot), and all of these differences play important roles in the behavior of archwires.[26–30] Hence, comparison of wires in PEAs and Begg appliances provides an excellent opportunity in clinical setup to examine the properties and behaviors of wires in two distinct types of brackets with the aforementioned fundamental biomechanical differences, which can truly test and compare the benchmark properties of these wires derived from laboratory setup alone. Therefore, the present study was designed to compare superelastic NiTi and multistranded (coaxial) stainless steel wires in PEAs and Begg appliances under moderate to severe crowding conditions of mandibular anterior dentition.

MATERIAL AND METHODS

In total, 180 participants were evaluated and scrutinized. Of these, 100 participants met the inclusion criteria and were enrolled in this nonrandomized, prospective clinical trial. Inclusion criteria were as follows:

- 12–18 years old
- Eruption of all mandibular teeth except second or third molars
- Symmetrical and uniform crowding (eg, no single tooth block out) of mandibular anterior segment
- No crowding in the posterior segments
- Moderate (Little's Irregularity Index score 4 mm to $\leq$ 6 mm) to severe crowding (Little's Irregularity Index score $>$ 6 mm to 9 mm) in mandibular anterior segment
- No anterior crossbite
- No severe deep bite, which may influence bracket placement on mandibular anterior dentition; interfere with leveling and alignment phase of treatment; or require any other mechanics for its correction (eg, sectional mechanics or bite blocks) other than continuous archwire mechanics
- No history of any medical problem or medication use that may influence the rate of tooth movement

Institutional approval and patient approvals were received for this study.

Sample size was calculated based on power analysis done using G power software version 2.0 (E Erdfelder, Psychologicsches Institut der Universitat, Bonn, Romestr. Germany) for one-way analysis of variance (ANOVA) test at alpha error probability of 0.05 and power of 90% to detect 40% (Cohen's large effect size $f = 0.4$) difference in clinically meaningful crowding reduction of 1 mm (SD $\pm$ 1 mm). Power analysis showed that total 96 participants were required, so it was decided to enroll more than the required number of participants for possible sample attrition.

The 100 participants selected were enrolled in the study after providing informed consent and were then distributed into four groups: superelastic NiTi PEA ($n = 25$), superelastic NiTi Begg ($n = 25$), multistranded (coaxial) stainless steel PEA ($n = 25$), and multistranded (coaxial) stainless steel Begg ($n = 25$). Based on diagnostic records analysis, comprehensive treatment planning was done, and all patients with severe crowding required extraction of mandibular first premolars bilaterally. During enrollment of study participants, numbers of extraction/nonextraction cases were balanced in all four groups, keeping in mind that extraction spaces affect crowding alleviation. All required extractions were done one week before the study commenced, and this time factor for extractions was also standardized because time elapsed between extraction and the beginning of fixed appliance mechanotherapy affects the rate of movement of teeth adjacent to the extraction space.

The intervention and subsequent follow-up were done by the first author. The following materials were used: 0.0175-inch multistranded stainless steel (straight length, six-stranded, coaxial: Dentaflex, Dentaurum, Newtown, PA, USA) and 0.016-inch superelastic NiTi (austenitic active preformed ovoid, superelastic archwire; 3M Unitek Corp, Monrovia, CA, USA)

Table 1. Demographic and Clinical Characteristics Data[a]

		PEA Superelastic NiTi (n = 24)	Begg Superelastic NiTi (n = 24)	PEA Multistranded (Co-ax) S.S (n = 25)	Begg Multistranded (Coaxial) Stainless Steel (n = 23)
Age	12–18 (years)	15 (1.91)	15.2 (1.92)	15.1 (1.96)	15.4 (2.13)
Sex	Male	12 (50%)	13 (54.2%)	13 (52%)	11 (47.8%)
	Female	12 (50%)	11 (45.8%)	12 (48%)	12 (52.2%)
Initial Crowding (T1)	Moderate (≤6 mm)	5 (0.48)	5.6 (0.39)	5.2 (0.54)	5.8 (0.46)
		12 (50%)	12 (50%)	12 (48%)	12 (52.2%)
	Severe (>6 mm)	8 (0.66)	7.7 (0.68)	7.1 (0.63)	7.8 (0.67)
		12 (50%)	12 (50%)	13 (52%)	11 (47.8%)
Extraction/Nonextraction	Extraction	12 (50%)	12 (50%)	13 (52%)	11 (47.8%)
	Nonextraction	12 (50%)	12 (50%)	12 (48%)	12 (52.2%)

[a] Data are means (standard deviation) or numbers (percent).

wires were used in the PEA with 0.022-inch × 0.028-inch slot twin brackets (Roth prescription, Gemini Metal Brackets, 3M Unitek Corp, Monrovia, CA, USA) and Begg appliance with standard Begg brackets (Accupoint .030, GAC International, Bohemia, NY). All these brackets were bonded as accurately as possible using light-cure composite resin (Transbond XT, 3M Unitek Corp, Monrovia, CA, USA) to avoid any bracket positioning error that could cause unwanted rotations or labiolingual discrepancies. The required length of multistranded (coaxial) stainless steel wire was contoured to the arch shape, and preformed superelastic NiTi was used as supplied. Researchers used 0.009-inch stainless steel ligatures and stage I brass lock pins (TP Orthodontics, Inc, LaPorte, IN, USA) to secures wires in the preadjusted edgewise and Begg brackets, respectively. At the end of study (six weeks), both superelastic NiTi and multistranded (coaxial) stainless steel wires were removed carefully and inspected for any visible change in morphology/shape, and a good-quality alginate impression was taken of the mandibular arch for indirect assessment of the reduction in crowding.

The outcome, reduction in crowding, was assessed indirectly from the mandibular cast using the Little's IR index[31] method wherein initial/pretreatment crowding (T1) and crowding at the end of study, that is, after six weeks (T2) were calculated. The difference between T1 and T2 provided the reduction in crowding (T1–T2). A calibrated Vernier caliper (manual type) with a least count of 0.1 mm was used, and each cast (pretreatment and poststudy) was measured twice independently by two trained lab technicians (blinded to the study). The mean of these measurements was taken as the amount of crowding. Measurement error was evaluated by repeating the measurements on 20 randomly selected study models by the first author, and statistical testing revealed high correlation among measurements.

The study was designed to see efficiency within a specified time period (six weeks) instead of taking a time to complete alignment approach to keep the patient's interest in mind because outcome was unpredictable. It would be unethical to unduly prolong the leveling and aligning phase and overall treatment duration if alignment achieved by any particular group was significantly less.

Statistical Analysis

All statistical analyses were done using SPSS package software (IBM SPSS Statistics, version 17.0, Chicago, IL). Demographic and clinical characteristics were investigated with descriptive statistics. One-way ANOVA was used to compare four groups for reduction in crowding (T1–T2). Linear regression

Table 2. Mean Reduction in Crowding (T1–T2) for Each Group[a]

Initial Crowding (T1)	Group	Mean (T1–T2)[b]	SD	95% Confidence Interval for Mean: Lower	Upper
Moderate (≤6 mm)	PEA superelastic NiTi	4.4	0.5	4.1	4.7
	Begg superelastic NiTi	4.3	0.4	4.1	4.6
	PEA multistranded (coaxial) stainless steel	4.1	0.7	3.6	4.5
	Begg multistranded (coaxial) stainless steel	3.4	0.5	3.1	3.7
Severe (>6 mm)	PEA superelastic NiTi	6.2	0.5	5.9	6.5
	Begg superelastic NiTi	6.3	0.8	5.9	6.7
	PEA multistranded (coaxial) stainless steel	5.8	0.5	5.5	6.1
	Begg multistranded (coaxial) stainless steel	2.7	0.4	2.5	3.0

[a] SD indicates standard deviation; PEA, preadjusted edgewise appliance; NiTi, nickel-titanium.

[b] Mean reduction in crowding (in millimeters).

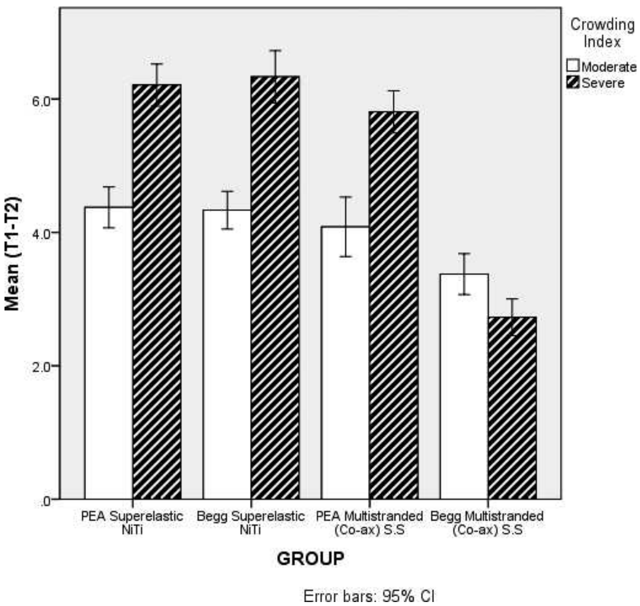

Figure 1. Comparison between groups for reduction in crowding (in millimeters).

analysis was used to evaluate the effect of initial crowding (T1) on reduction in crowding (T1–T2). A value of $P < .05$ was considered statistically significant.

RESULT

During the study, one participant was lost to follow-up, and follow-up was discontinued in another three patients because of bond failure in the mandibular anterior dentition area. A total of 96 participants (48 male, 48 female) 12 to 18 years of age (mean age 15.2 years $\pm$ 1.95) were analyzed for the results. Demographic and clinical characteristics are shown in Table 1.

Table 2 and Figure 1 show the mean reduction in crowding (T1–T2) for each group, and Table 3 shows the results of ANOVA. Under both moderate and severe crowding conditions, the mean reduction in crowding for the multistranded (coaxial) stainless steel Begg group was significantly less compared with that of the other three groups, as shown with the following statistics: $F\ (3, 44) = 8.896$, $P < .001$ in moderate crowding; $F\ (3, 44) = 122.341$, $P < .001$ in severe crowding; and effect size (ω) of 0.57 and 0.93 in moderate and severe crowding, respectively.

Linear regression analysis (Tables 4 and 5 and Figure 2) demonstrated significant ($P < .05$) positive correlation between initial crowding (T1) and reduction in crowding (T1–T2), except in the multistranded (coaxial) stainless steel Begg group. In the multistranded (coaxial) stainless steel Begg group, as the

Table 3. Comparisons Between Groups for Mean Reduction in Crowding (T1–T2)

Initial Crowding (T1)	(I) Group	(J) Group	Mean Difference (I-J)	Significance	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Moderate (≤6 mm)	PEA superelastic NiTi	Begg superelastic NiTi	0.23	.84	−0.56	0.64
		PEA multistranded (coaxial) stainless steel	0.29	.70	−0.31	0.89
		Begg multistranded (coaxial) stainless steel	0.98*	.00	0.40	1.60
	Begg superelastic NiTi	PEA superelastic NiTi	−0.023	.84	−0.64	0.56
		PEA multistranded (coaxial) stainless steel	0.25	.83	−0.35	0.85
		Begg multistranded (coaxial) stainless steel	0.95*	.00	0.36	1.56
	PEA multistranded (coaxial) stainless steel	PEA superelastic NiTi	−0.29	.70	−0.89	0.31
		Begg superelastic NiTi	−0.25	.83	−0.85	0.35
		Begg multistranded (coaxial) stainless steel	0.70*	.01	0.11	1.31
	Begg multistranded (coaxial) stainless steel	PEA superelastic NiTi	−0.98*	.00	−1.60	−0.40
		Begg superelastic NiTi	−0.95*	.00	−1.56	−0.36
		PEA multistranded (coaxial) stainless steel	−0.70*	.01	−1.31	−0.11
Severe (>6 mm)	PEA superelastic NiTi	Begg superelastic NiTi	−0.13	.99	−0.71	0.46
		PEA multistranded (coaxial) stainless steel	0.40	.30	−0.17	0.97
		Begg multistranded (coaxial) stainless steel	3.48*	.00	2.89	4.08
	Begg superelastic NiTi	PEA superelastic NiTi	0.13	.99	−0.46	0.71
		PEA multistranded (coaxial) stainless steel	0.53	.09	−0.05	1.10
		Begg multistranded (coaxial) stainless steel	3.60*	.00	3.01	4.20
	PEA multistranded (coaxial) stainless steel	PEA superelastic NiTi	−0.40	.30	−0.97	0.17
		Begg superelastic NiTi	−0.53	.09	−1.10	0.05
		Begg multistranded (coaxial) stainless steel	3.08*	.00	2.50	3.66
	Begg multistranded (coaxial) stainless steel	PEA superelastic NiTi	−3.48*	.00	−4.08	−2.89
		Begg superelastic NiTi	−3.60*	.00	−4.20	−3.01
		PEA multistranded (coaxial) stainless steel	−3.08*	.00	−3.66	−2.50

[a] SD indicates standard deviation; PEA, preadjusted edgewise appliance; NiTi, nickel-titanium.
* Mean difference is significant at $P < .05$.

Table 4. Linear Regression Analysis (Overall) Model Summary[a,b]

Group	Model	R	R^2	Adjusted R^2	SE of the Estimate	Change Statistics: F Change	df1	df2	Significant F Change
PEA superelastic NiTi	1	.961[a]	.924	.920	.2967	267.178	1	22	.000
Begg superelastic NiTi	1	.928[a]	.862	.856	.4362	137.453	1	22	.000
PEA multistranded (coaxial) stainless steel	1	.947[a]	.897	.892	.3496	199.835	1	23	.000
Begg multistranded (coaxial) stainless steel	1	.581[a]	.337	.306	.4582	10.692	1	21	.004

[a] Predictors: (constant), T1.
[b] SE indicates standard error; PEA, preadjusted edgewise appliance; NiTi, nickel-titanium.

initial crowding (T1) increased, the reduction in crowding (T1–T2) decreased proportionately, displaying a negative correlation.

DISCUSSION

In PEA, no statistically significant difference was found for reduced crowding by both wires under moderate and severe crowding conditions (Table 3), and this finding is in accordance with that of previous studies.[10,23,24] On the other hand, superelastic NiTi very significantly outweighed multistranded (coaxial) stainless steel wire in the Begg appliance for reduction in crowding (Table 3). Linear regression analysis demonstrated that as the severity of crowding increased, the aligning capability of multistranded (coaxial) stainless steel wires in the Begg appliance rapidly decreased (Figure 2). Visual inspection of wires at the end of the study clearly showed that in the Begg appliance, multistranded (coaxial) stainless steel wire distorted under both moderate and severe crowding conditions, but this damage was much greater in conditions of severe crowding (Figures 3).

These differences in efficiency and behavior of superelastic NiTi and multistranded (coaxial) stainless steel wire can be explained by the different physical properties of these two wires combined with the different design features of the PEA and the Begg appliance. In the PEA, the greater mesiodistal width of the bracket gives better support to the wire and prevents a concentration of stresses, thereby preventing distortion of the wire. On the other hand, the mesiodistally small Begg bracket causes concentration of stresses because the wire comes out of the vertical slot with relatively sharp edges; hence, it distorts the multistranded (coaxial) stainless steel wire owing to its low spring-back value. This damage is greater because the severity of the crowding increases

Table 5. Linear Regression Coefficients for Moderate and Severe Crowding Subgroups[a,b]

Group	Initial Crowding (T1)	Model		Unstandardized Coefficients B	SE	Standardized Coefficients Beta	t	P	95% Confidence Interval for B: Lower Bound	Upper Bound
PEA superelastic NiTi	Moderate ≤6 mm)	1	(Constant)	0.6	1.2		0.5	.6	−2.1	3.3
			T1	0.7	0.2	0.7	3.2	.01*	0.2	1.2
	Severe (>6 mm)	1	(Constant)	1.0	0.9		1.2	.3	−1.0	3.1
			T1	0.7	0.1	0.9	5.7	.00*	0.4	0.9
Begg superelastic NiTi	Moderate (≤6 mm)	1	(Constant)	0.4	1.1		0.4	.7	−1.9	2.8
			T1	0.7	0.2	0.8	3.7	.00*	0.3	1.2
	Severe (>6 mm)	1	(Constant)	1.0	1.4		0.7	.5	−2.2	4.1
			T1	0.7	0.2	0.8	3.8	.00*	0.3	1.1
PEA multistranded (coaxial) stainless steel	Moderate (≤6 mm)	1	(Constant)	−1.7	1.4		−1.2	.3	−4.9	1.5
			T1	1.1	0.3	0.8	4.1	.00*	0.5	1.7
	Severe (>6 mm)	1	(Constant)	1.0	1.3		0.8	.4	−1.8	3.8
			T1	0.6	0.2	0.8	3.8	.00*	0.3	1.0
Begg multistranded (coaxial) stainless steel	Moderate (≤6 mm)	1	(Constant)	2.5	1.7		1.4	.2	−1.4	6.4
			T1	0.2	0.3	0.2	0.5	.6	−0.6	0.9
	Severe (>6 mm)	1	(Constant)	4.3	1.5		2.8	.0	0.9	7.7
			T1	−0.2	0.2	−0.32[Ŧ]	−1.0	.3	−0.6	0.2

[a] Dependent variable: (T1–T2); *significant at $P > .05$; Ŧ negative coefficient between T1 and (T1–T2) Model 1. Predictors: (Constant), T1.
[b] SE indicates standard error; PEA, preadjusted edgewise appliance; NiTi, nickel-titanium.

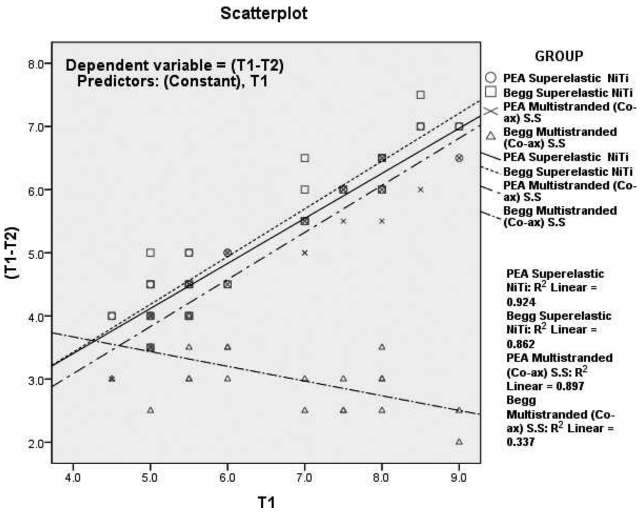

Figure 2. Linear regression (overall) scatterplot with slopes and fit line.

because of the decreased interbracket distance, which further decreases the springy characteristics of wires. The physical property that makes multistranded (coaxial) stainless steel wire vulnerable to distortion in these sharp bending situations is its low strength and spring-back value compared with Ni-Ti–based alloys, especially superelastic NiTi.[32–39] The resulting distortion of multistranded (coaxial) stainless steel wire in Begg appliances increases friction because of the increased bracket binding angle. This further decreases the aligning potential because, during the aligning phase, brackets travel along the archwire.[8]

The difference in interbracket distance[28,30] between the PEA and the Begg appliance may affect wire flexibility and subsequent behavior of archwire during the aligning phase of treatment, but this factor is of limited or no importance for wires demonstrating property of hysteresis, as seen in superelastic NiTi alloys.[12] The increased interbracket distance in the Begg appliance might have increased flexibility of multistranded (coaxial) stainless steel wire, but it was still not sufficient to prevent permanent deformation because, considering a linearly displaced and rotated tooth, interbracket distance is smaller in cases of rotated teeth, and rotations are a common feature of severe crowding in mandibular anterior dentition. This thereby limits any advantage of the increased interbracket distance that is usually associated with the Begg appliance.

Reduction in crowding (T1–T2) for all groups, except multistranded (coaxial) stainless Begg, was greater in cases of severe crowding compared with cases of moderate crowding. This difference is most likely due to extraction spaces available because all severe crowding cases required bilateral extraction of mandibular first premolars. Resulting available space eases the

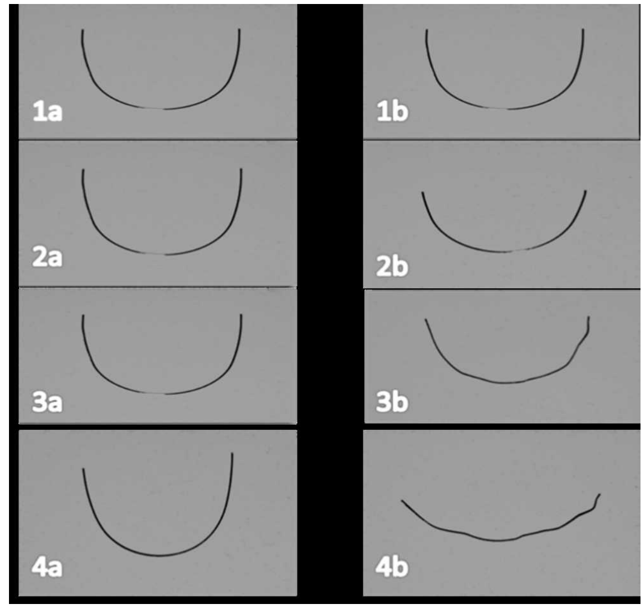

Figure 3. Shape and morphology of superelastic NiTi wire in preadjusted edgewise appliance (PEA) (1a: before placement; 1b: six weeks later) and Begg appliance (2a: before placement; 2b: six weeks later). Shape and morphology of multistranded (coaxial) stainless steel wire in PEA (3a: before placement; 3b: six weeks later) and Begg appliance (4a: before placement; 4b: six weeks later).

unraveling of crowding by allowing teeth to move into the spaces and also due to increased inter-bracket distance bilaterally.[24] The multistranded (coaxial) stainless steel wire in the Begg appliance could not use this favorable condition for de-crowding because the wire was permanently distorted and ineffective.

Limitations of the trial were selection bias (because it was not a randomized, controlled trial) and the duration of the study, and although the trial was nonrandomized, all groups were well matched for demographic characteristics and amount of initial crowding. It has been claimed that superelastic NiTi wires remain active over a longer period, and their efficiency can be increased by retying after 6 to 8 weeks.[40] Therefore, the superiority of the superelastic NiTi over the multistranded (coaxial) stainless steel wire in the Begg appliance may become even more pronounced with time because a distorted multistranded (coaxial) stainless steel wire will be passive without adding to alignment, whereas a retied superelastic NiTi wire will be as effective as on day one of placement. Therefore, further study with a longer duration is desirable.

CONCLUSIONS

- In the PEA, superelastic NiTi and multistranded (coaxial) stainless steel wires are comparable for efficiency to alleviate mandibular anterior crowding under both moderate and severe crowding conditions.

- In the Begg appliance, superelastic NiTi significantly outweighed multistranded (coaxial) stainless steel wire for efficiency, and the difference was statistically highly significant under severe crowding condition.
- Extraction spaces in severe crowding cases eased the alleviation of mandibular anterior crowding.

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