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The effect of different clinical recycling methods on load deflection properties of super-elastic and thermal nickel–titanium orthodontic arch wires: A comparative assessment

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Abstract

INTRODUCTION: Repeated clinical use of arch wires requires sterilization and may result in alteration of the properties of the wires as they get subjected to corrosion and cold working. Therefore, the present study aimed to assess the effects of different clinical recycling methods on the load-deflection properties of super-elastic and thermal nickel–titanium orthodontic arch wires.

MATERIALS AND METHODS: A total of 50 0.014" round nickel–titanium orthodontic wires [Group I: super-elastic nickel–titanium (n = 25) and Group II: thermal nickel–titanium wires (n = 25)] were tested for changes in their load deflection properties after three different recycling methods, that is, dry heat sterilization, autoclave, and cold sterilization. For each group, five wires as received from the manufacturer were taken as control (T0), and the rest of the 20 wires were placed intra-orally for a duration of one cycle of clinical use (T1). Five wires out of these were subjected to 3-point bending tests, and the rest of the wires were subjected to different recycling methods. Load deflection properties of recycled wires were measured with an Instron universal testing machine. The results were tabulated, and the data were analyzed by analysis of variance (ANOVA) with the Tukey *post hoc* test.

RESULTS: Statistically, no significant difference was found in the super-elastic group between samples recycled by dry heat, autoclave, and cold sterilization when compared with as-received super-elastic NiTi up to 2.5 mm of deflection. A highly significant difference was found between as-received thermal NiTi group (83.51 ± 6.49 N/mm) and samples recycled by dry heat (53.73 ± 4.72 N/mm), autoclave (45.38 ± 4.37 N/mm), and cold sterilization (48.44 ± 3.12 N/mm) at 0.5 mm of deflection.

CONCLUSION: Among thermal NiTi, any of the sterilization methods could opt at all deflections. For super-elastic NiTi, at higher deflections or in cases of crowding of more than 2.5 mm, cold sterilization should be the method of choice, whereas any sterilization method can be used at deflections less than 2.5 mm.

Keywords:
Clinical recycling, load deflection rate, superelastic NiTi, thermal NiTi

Introduction

The awareness of severe diseases transmitted via cross-infection has increased among the public and medical professionals. This has resulted in a closer examination of sterilization procedures, and orthodontic wires are no exception to it.[1] Sterilization, according to American

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Dental Association (ADA), can be classified into dry heat, moist heat, and cold sterilization. Although orthodontic wires come in individually sealed bags to avoid cross-contamination, manufacturers usually recommend sterilizing them before and in between use.[2] The combined effect of repeated clinical use and sterilization may alter the properties of the wire as it is subjected to corrosion and cold working.[3] Optimum orthodontic tooth movement requires a low magnitude and a constant duration of the force. This is determined by the load deflection rate (LDR) of the arch wire, which is the external load needed for unit deformation.[4] Nickel–titanium (NiTi) alloys are the most sought-after arch wires in the initial stages of orthodontic treatment because of their low LDR and remarkable super-elastic properties. This characteristic allows them to exert nearly the same amount of force irrespective of the activation of the wire, thus providing a constant force of low magnitude for a given time duration.[5] Although clinical recycling saves chair-side time and prevents the wastage of wires, the load deflection property of arch wires should not be altered. Hence, this study aimed to assess the effects of different clinical recycling methods, that is, moist heat sterilization (autoclaving), dry heat sterilization (DHS), and cold sterilization, on the load deflection property of super-elastic and thermal NiTi orthodontic arch wires.

Materials and Methods

Samples selected for this study were prepared 1 month post leveling and alignment from arch wires that had been used in patients 13–25 years of age with a full complement of teeth and crowding of ≤4 mm. NiTi orthodontic wires (0.014″ round) were tested to compare their mechanical properties. The sample (25 per group) comprised super-elastic NiTi and heat-activated NiTi wires. For each group, five wires, as received from the manufacturer, were taken as control (T0) and were subjected to 3-point bending tests on the Instron universal testing machine in collaboration with the Indian Institute of Technology-Kanpur (IIT-K). The remaining 20 wires were loaded in the patients for a duration of 1 month. The wires were retrieved and cleaned with 70% isopropanol-soaked cotton gauze to remove surface debris. Of these, five wires were subjected to 3-point bending tests, and the rest were placed for sterilization (five in each group). Steam autoclaving was accomplished at 121°C and 15 psi for 30 minutes, DHS using a hot air oven was performed at 235°C for 20 minutes, and cold sterilization was done using Quitanet Plus by placing the wire in the solution for 10 minutes. In each scenario, for the 3-point bending test, the wires were tested with metal brackets (victory 3M) mounted on a customized acrylic jig in which the load site simulated a mal-aligned lateral incisor of 14 mm length between the midpoints of the brackets. This inter-bracket distance was derived from typical tooth dimensions for a maxillary permanent dentition. The super-elastic wires were tested at room temperature, and the heat-activated wires were tested in a 96 ± 2°C water bath [Figure 1]. The Instron universal testing machine was operated at a crosshead speed of 1 mm per minute with a 50 N load cell with loadings for 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, and 3.0 mm. The unloading curve was measured from the passive position to activations of 3.0 mm, 2.5 mm, 2.0 mm, 1.5 mm, 1.0 mm, and 0.5 mm and then back to 0. The data were summarized as mean ± standard deviation. The groups were compared using two-way analysis of variance, followed by Tukey's post-hoc test for intra-group and inter-group comparisons. A two-tailed ($\alpha = 2$) P value of <0.05 ($P < 0.05$) was considered statistically significant. All analyses were performed on STATITICA (Windows version 6.0) software.

Results

The present study compares the effect of different clinical recycling methods on the load deflection properties of super-elastic and thermal nickel–titanium (NiTi) orthodontic wires. For each group, wires were studied as received after 1 month of loading and then by three recycling methods. For each group, LDRs of five samples (n = 5) at six different deflections (0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, and 3.0 mm) were measured on both loading and unloading and have been compared statistically [Tables 1, 2 and Figures 2, 3]. Loading showed an insignificant difference in the super-elastic group between samples recycled by dry heat, autoclave, and cold sterilization and also when compared with as-received superelastic NiTi for all levels of deflection. A statistically high significant difference was found between as-received thermal NiTi group and samples recycled by dry heat, autoclave, and cold sterilization for all levels of deflection ($P < 0.001$) [Table 3]. Unloading showed an insignificance difference among the super-elastic group between samples recycled by dry heat, autoclave, and cold sterilization and also when compared with as-received super-elastic NiTi at all levels of deflection.

A highly significant difference was found between as-received thermal NiTi group and samples recycled

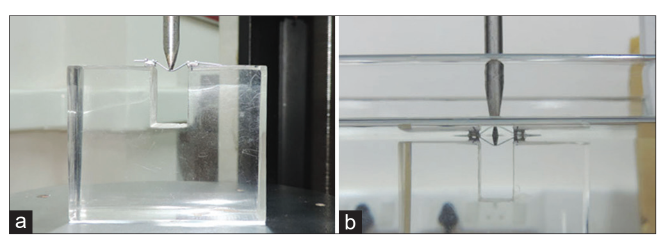

Figure 1: (a) Superelastic NiTi during testing. (b) Thermal NiTi during testing

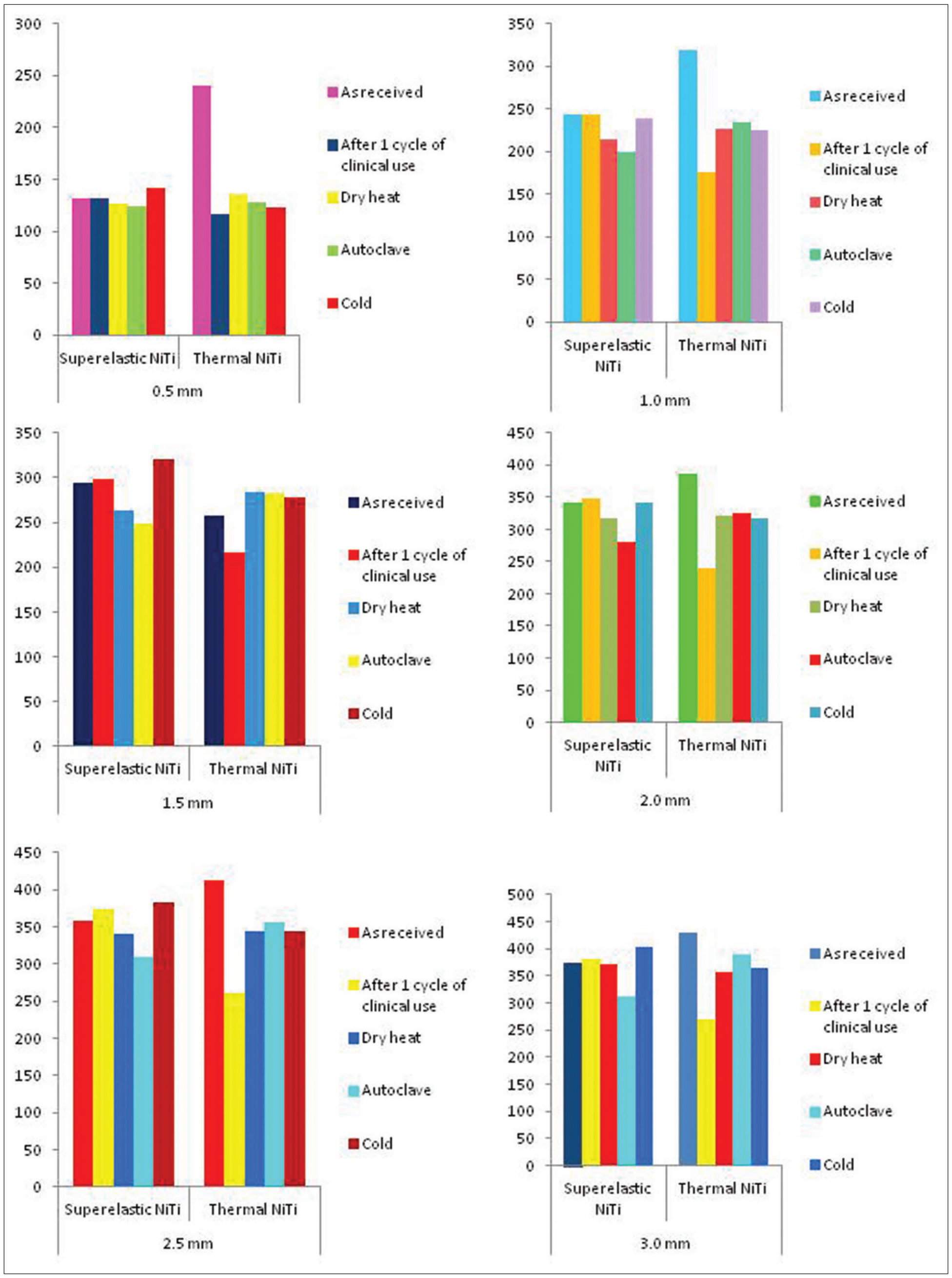

Figure 2: Comparison of mean LDR between methods at various deflections on loading for each group

by dry heat, autoclave, and cold sterilization ($P < 0.001$) at 0.5 mm, while no significant difference was found in the thermal group between samples recycled by dry heat, autoclave, and cold sterilization and also when compared with as-received thermal NiTi at deflections from 1.0 mm onward [Table 4].

Discussion

When subjected to loading, super-elastic wires demonstrate a unique non-linear loading curve at various deflections. Although this property has been referred to as "super-elasticity" in orthodontic literature, in the metallurgic context, this phenomenon is known as "pseudo-plasticity" during loading and "pseudo-elasticity" during unloading.[6] Furthermore, other physical properties, such as extremely low flexural rigidity, high working range, and corrosion resistance, make the NiTi alloy attractive to orthodontists.[7] NiTi wires are also used during the finishing stages[4] because some teeth require minor positional changes and some require alterations in their root position.

Fabrication of the various bends in NiTi wires and customized arch wires at various clinical stages in lingual orthodontics requires clinical chair-side time, thereby

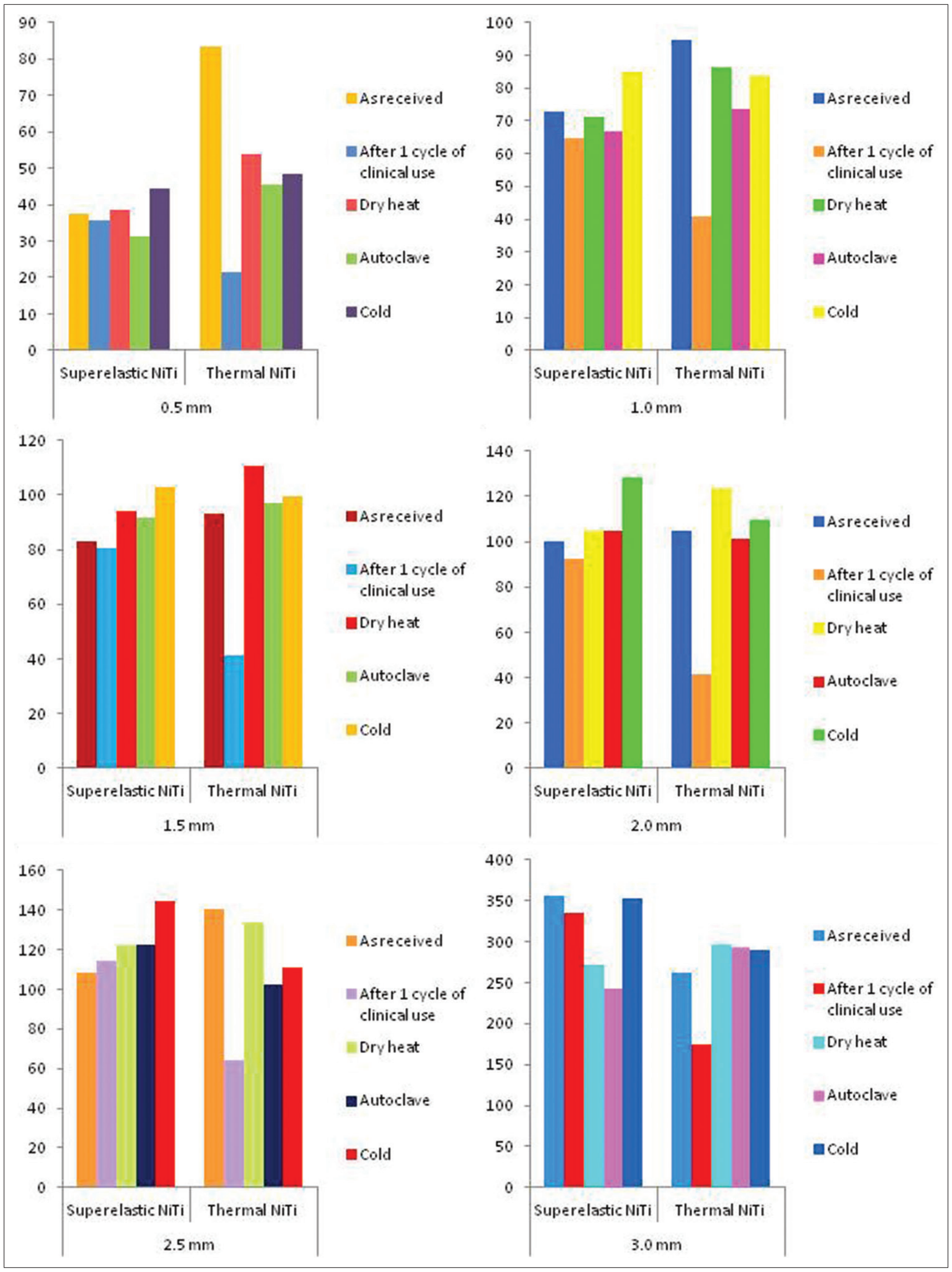

Figure 3: Comparison of mean LDR between methods at various deflections on unloading for each group

necessitating clinical recycling of these arch wires. One more drawback of these arch wires is their relatively high cost.[2-3,8] Therefore, owing to their desirable mechanical properties but high cost, many clinicians resort to recycle these wires. The ability to recycle these arch wires depends on the effective sterilization of the wire prior to reuse without resulting in deterioration of its clinical properties. When a wire is deflected for placement in a bracket on a malaligned tooth, it is subjected to loading. The unloading of the wire represents its spring back and provides the force required to cause a biological tissue response that tends to move the tooth into proper alignment. Therefore, the forces associated with the wire during unloading provide insights into its potential clinical behavior.[8,9]

For super-elastic NiTi, comparison of T0 and T1 showed an increased loading force at T1 compared with that at T0, whereas the unloading force at T1 was decreased compared with that at T0, although the observed changes were not statistically significant. This change could be attributed to the increase in wire stiffness[2,3] because of work hardening due to masticatory forces, other components of the oral environment (such as pH), and the use of acidic solutions (aerated drinks, citrus fruits, etc.), thus reducing the pseudo-plasticity

Table 1: Deflection-wise LDR (Mean ± SD) of two groups at five different methods of loading

Deflection	Group	As received (T0)	After 1 cycle of clinical use (T1)	Dry heat (T2d)	Autoclave (T2a)	Cold (T2c)
0.5 mm	Superelastic NiTi	131.54±5.81	132.05±5.02	126.44±5.00	123.82±4.54	142.25±6.31
	Thermal NiTi	240.65±6.80	116.90±6.23	135.11±5.51	127.97±6.39	123.38±6.65
1.0 mm	Superelastic NiTi	244.23±6.19	244.22±5.97	214.65±5.63	198.33±7.30	239.63±7.10
	Thermal NiTi	318.66±6.71	176.41±6.92	226.04±5.38	234.10±5.23	225.35±5.95
1.5 mm	Superelastic NiTi	294.69±6.84	298.77±4.62	263.59±6.39	249.32±6.71	320.19±7.32
	Thermal NiTi	257.91±6.20	217.20±5.59	283.99±5.62	282.46±7.49	278.38±5.25
2.0 mm	Superelastic NiTi	340.58±6.24	348.23±5.70	317.64±3.71	280.93±4.76	342.11±6.14
	Thermal NiTi	385.96±3.12	239.63±6.80	320.70±4.37	324.77±6.71	316.11±4.62
2.5 mm	Superelastic NiTi	357.40±6.39	373.72±6.18	340.38±5.02	307.64±4.53	383.41±5.20
	Thermal NiTi	411.96±3.75	261.55±5.79	344.23±5.75	356.39±4.70	343.67±4.81
3.0 mm	Superelastic NiTi	373.72±4.11	380.86±5.70	371.62±6.02	311.52±5.70	401.76±4.27
	Thermal NiTi	429.91±5.97	270.83±5.28	357.40±3.12	388.51±4.84	363.01±5.49

Table 2: Deflection-wise LDR (Mean±SD) of two groups by five different methods at unloading

Deflection	Group	As received (T0)	After 1 cycle of clinical use (T1)	Dry heat (T2d)	Autoclave (T2a)	Cold (T2c)
0.5 mm	Superelastic NiTi	37.34±4.06	35.69±6.24	38.54±5.20	31.10±6.12	44.56±7.16
	Thermal NiTi	83.51±6.49	21.50±5.88	53.73±4.72	45.38±4.37	48.44±3.12
1.0 mm	Superelastic NiTi	72.81±13.10	64.85±8.51	71.38±10.51	66.79±10.62	85.14±13.75
	Thermal NiTi	94.83±7.49	40.69±13.93	86.29±9.03	73.42±11.24	83.62±10.64
1.5 mm	Superelastic NiTi	82.83±14.85	80.56±13.74	94.32±14.36	91.77±11.24	102.99±13.71
	Thermal NiTi	93.30±14.36	41.20±14.80	110.57±11.13	96.87±13.37	99.73±12.78
2.0 mm	Superelastic NiTi	99.93±15.58	92.28±13.21	105.03±14.70	104.52±12.44	128.22±16.30
	Thermal NiTi	105.03±12.49	41.30±15.24	123.38±13.54	101.46±11.82	109.69±11.08
2.5 mm	Superelastic NiTi	108.60±14.01	114.21±12.84	122.54±14.94	122.36±14.01	144.29±11.01
	Thermal NiTi	140.21±11.83	64.24±14.99	134.09±13.89	102.48±10.54	111.15±11.24
3.0 mm	Superelastic NiTi	355.37±11.86	335.22±13.82	272.26±17.12	243.20±13.11	352.31±12.23
	Thermal NiTi	262.06±14.99	174.06±16.77	295.71±16.88	293.16±15.95	290.07±16.50

of the wire. The difference in the loading and unloading curves represents the mechanical hysteresis of the material.[10]

The difference between T1 and T2 signifies the effect of recycling on the wire. In the super-elastic group, a decrease was noted in the loading values after DHS of the wire (T1 > T2d). This decrease indicates that the wire has gained elasticity after DHS, and hence, the force applied to engage the wire decreases. A decrease in the loading values post sterilization suggests that the stresses incorporated owing to the effects of the oral environment and masticatory forces have been reduced after DHS,[4] thus allowing the wire to acquire its pseudo-plastic property. An increase in the unloading force after DHS (T2d > T1) was observed at all deflections, except at 3.0 mm, at which it decreased, although all changes were statistically insignificant. This finding suggests that DHS has tried to compensate for the effects of the oral environment on the wire, which is evident from the large hysteresis loss when T0 and T1 were compared.[10]

A decrease in the loading forces (T1 > T2a) was seen at all deflections, but an increase was observed in the unloading force (T2a > T1) at all deflections, except at 0.5 mm and 3.0 mm, in the autoclaved samples. An increase was perceived in LDR post-cold sterilization in the super-elastic group when compared with the wire after one cycle of clinical use (T2c > T1). This could be ascribed to the increase in the stiffness of the wire owing to the increase in roughness and pitting type of corrosion.[3] This finding agrees with that from a study by Kapila and Reichfold,[8] who observed a decrease in unloading forces at lower deflections but an increase at deflections of >0.6 and up to 1.8 mm. Hence, the aberrant behavior seen at 3.0 mm may be due to elastic deformation of the M-active phase.

These findings differ from those of Mayhew and Kusy,[11] who observed no changes in LDR after recycling, and also from those of Khatieeb *et al.*,[12] who found a decrease in the unloading forces of NiTi post DHS. Comparison of T0 and T2 showed a statistically non-significant change in loading and unloading values at all deflections, except the unloading LDR at 3.0 mm, for groups sterilized using DHS and autoclaving. In these groups, the unloading force at 3.0 mm showed a highly significant steep decrease, which could be explained by the elastic deformation of the martensitic active phase.[4] These changes could be attributed to the cumulative effect of the masticatory force, the effects of the oral environment,

Table 3: For each deflection and group, comparison (p value) of mean LDR for loading of wires between methods by Tukey test

Comparisons	Deflection- 0.5 mm		Deflection- 1.0 mm		Deflection- 1.5 mm		Deflection- 2.0 mm		Deflection- 2.5 mm		Deflection- 3.0 mm	
	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi
(T0) vs. (T1)	1.000	<0.001	0.978	<0.001	1.000	<0.001	0.996	<0.001	1.000	<0.001	0.527	<0.001
(T1) vs. (T2d)	0.998	<0.001	0.994	<0.001	0.834	<0.001	0.897	<0.001	0.990	<0.001	0.985	<0.001
(T1) vs. (T2a)	0.941	<0.001	1.000	0.001	0.944	<0.001	0.918	<0.001	0.991	0.001	0.078	<0.001
(T1) vs. (T2c)	0.267	<0.001	0.140	<0.001	0.238	<0.001	0.006	<0.001	0.023	<0.001	0.734	<0.001
(T0) vs. (T2d)	1.000	<0.001	1.000	0.965	0.936	0.589	1.000	0.530	0.793	0.999	0.685	0.031
(T0) vs. (T2a)	0.729	<0.001	0.997	0.099	0.987	1.000	1.000	1.000	0.805	0.002	0.058	0.061
(T0) vs. (T2c)	0.546	<0.001	0.754	0.840	0.374	0.999	0.063	1.000	0.004	0.032	1.000	0.127
(T2d) vs. (T2a)	0.504	0.344	1.000	0.708	1.000	0.838	1.000	0.288	1.000	0.014	0.100	1.000
(T2d) vs. (T2c)	0.767	0.872	0.627	1.000	0.990	0.955	0.221	0.852	0.233	0.177	<0.001	1.000
(T2a) vs. (T2c)	0.012	0.996	0.242	0.901	0.944	1.000	0.198	0.994	0.224	0.987	<0.001	1.000

Table 4: For each deflection and group, comparison (p value) of mean LDR for unloading of wires between methods by Tukey test

Comparisons	Deflection- 0.5 mm		Deflection- 1.0 mm		Deflection- 1.5 mm		Deflection- 2.0 mm		Deflection- 2.5 mm		Deflection- 3.0 mm	
	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi	Superelastic NiTi	Thermal NiTi
(T0) vs. (T1)	1.000	<0.001	0.978	<0.001	1.000	<0.001	0.996	<0.001	1.000	<0.001	0.527	<0.001
(T1) vs. (T2d)	0.998	<0.001	0.994	<0.001	0.834	<0.001	0.897	<0.001	0.990	<0.001	<0.001	<0.001
(T1) vs. (T2a)	0.941	<0.001	1.000	0.001	0.944	<0.001	0.918	<0.001	0.991	0.001	<0.001	<0.001
(T1) vs. (T2c)	0.267	<0.001	0.140	<0.001	0.238	<0.001	0.006	<0.001	0.023	<0.001	0.734	<0.001
(T0) vs. (T2d)	1.000	<0.001	1.000	0.965	0.936	0.589	1.000	0.530	0.793	0.999	<0.001	0.031
(T0) vs. (T2a)	0.729	<0.001	0.997	0.099	0.987	1.000	1.000	1.000	0.805	0.002	<0.001	0.061
(T0) vs. (T2c)	0.546	<0.001	0.754	0.840	0.374	0.999	0.063	1.000	0.004	0.032	1.000	0.127
(T2d) vs. (T2a)	0.504	0.344	1.000	0.708	1.000	0.838	1.000	0.288	1.000	0.014	0.100	1.000
(T2d) vs. (T2c)	0.767	0.872	0.627	1.000	0.990	0.955	0.221	0.852	0.233	0.177	<0.001	1.000
(T2a) vs. (T2c)	0.012	0.996	0.242	0.901	0.944	1.000	0.198	0.994	0.224	0.987	<0.001	1.000

and the effect of sterilization on the LDR of the wire. The findings observed post sterilization were in concordance with those of Kapila,[3] who detected an increase in the loading and unloading forces of the wire after clinical recycling. The present finding disagrees with the results of Mayhew and Kusy[11] and Khatieeb *et al*.,[12] who found a decrease in the unloading forces of NiTi post DHS. The investigation by Cherukuri *et al*.[13] is also in agreement with our study and Pernier *et al*.,[14] who did not perceive any change in LDR after sterilization. The values of T2d, T2a, and T2c indicate a non-significant change in the unloading curve of super-elastic NiTi at all deflections among the three sterilization methods, except at 3.0 mm deflection, at which cold sterilization showed minimal changes.

Heat-activated wires gained popularity because of their ability to be easily engaged in malaligned brackets at room temperature.[15] The forces exerted by the wire are proportional to the difference between its transformation temperature and its working temperature. Hence, heat-activated arch wires tend to impart less force than conventional NiTi arch wires.[16] However, in our study, as-received thermal NiTi showed higher loading and unloading values than as-received super-elastic NiTi at all deflections. Thermal NiTi exhibited a decrease in loading and unloading values when compared with as-received wires (T0), and the difference was statistically significant. This could be attributed to hysteresis loss when exposed to one cycle of clinical use. This observation was unlikely when compared with the super-elastic group, which showed minimal change at T1. This finding further suggests that super-elastic wires experience less hysteresis loss during the clinical cycle than thermal NiTi for the same duration of time. The difference between T1 and T2 gives the effect of recycling on the wire after one cycle of clinical use. This is one of the most important parameters that a clinician should consider when subjecting the wire to clinical recycling. This difference between T1 and T2 will aid the clinician in understanding whether the recycling method is causing any positive or negative change in the load deflection properties of the wire meant to be reused. Thermal NiTi showed a similar response to the sterilization procedures as super-elastic wires. The comparison of T0 and T2 helped in answering this question. Highly significant differences in the values of wires recycled by either of the methods when compared with as-received wires was observed at 0.5 mm of deflection. When subjected to 0.5 mm of deflection, recycled wires recorded the least loading and unloading values. These findings imply that although the loading values of recycled wires were less than those of as-received wires at all deflections, the unloading values increased with the increase in the amount of deflection from 0.5 mm to 3 mm. The combined effects of clinical use and sterilization may subject the wires to corrosion and cold working, with a resultant alteration in their properties.[2,3,8,17] These changes could be attributed to the cumulative effects of the masticatory force, effects of the oral environment, and effects of sterilization on the LDR of the wire. Comparison of T2d, T2a, and T2c revealed a statistically non-significant change in the unloading curve of thermal NiTi at all deflections among the three sterilization methods. Hence, for thermal NiTi, any of the three sterilization methods could be used at all deflections.

Conclusions

This study assessed the effects of different clinical recycling methods on the load deflection properties of super-elastic and thermal nickel–titanium orthodontic arch wires, and it can be concluded that:

1. In the super-elastic group, the unloading forces after one cycle of clinical use (4 weeks ± 1 week) (T1) were decreased in comparison to as-received wires (T0) even though the changes observed were statistically non-significant.
2. In the thermal NiTi group, a statistically highly significant decrease in the unloading forces after one cycle of clinical use (T1) when compared to as-received wires (T0) was observed.
3. Considering the unloading curves, different recycling methods, that is, dry heat sterilization, autoclaving, and cold sterilization did not alter the load deflection properties of super-elastic NiTi wires up to deflections of 2.5 mm. However, if considering a deflection of 3 mm, cold sterilization should be the method of choice as DHS and autoclave produced lower unloading forces than as-received wires (T0), and this difference was statistically significant.
4. For the thermal NiTi group, wires should always be sterilized post one cycle of clinical use as it helps to regain the loss in unloading forces. Different recycling methods appeared to have similar effects for all levels of deflection; however, for 0.5 mm of deflection, any of the recycling methods failed to regain the lost properties.

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Conflicts of interest

There are no conflicts of interest.

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