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Effect of dry heat and steam sterilization on load-deflection characteristics of β-titanium wires: An *in vitro* study

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ABSTRACT

Background: Sterilization techniques could affect the characteristics of orthodontic wires. The aim of the present study was to evaluate the effect of steam and dry heat sterilization techniques on load-deflection behavior of five types of β-titanium alloy wires.
Materials and Methods: The samples consisted of 30 straight lengths of five types of β-titanium alloy wires: Titanium Molybdenum Alloy (TMA) Low Friction (TMAL), TMA Low Friction Colored (HONE), Resolve (RES), BetaForce (BETA), and BETA CNA (CNA). Thirty wire segments were divided into three groups of 10. Group 1 was the control group and the group 2 samples were sterilized by dry heat in an oven (60 minutes at 160°C) and group 3 by steam in an autoclave (15 minutes at 121°C). Then all the wire samples underwent a three-point bending test in a testing machine to evaluate load-deflection properties. Data was analyzed by repeated measures ANOVA and Scheffé's test ($\alpha = 0.05$).
Results: The results showed that dry heat sterilization significantly increased force levels during both loading and unloading of CNA, BETA and RES and during loading of HONE ($P < 0.05$). Steam sterilization significantly increased force levels during both loading and unloading of BETA and during unloading of HONE ($P < 0.05$), with no effects on the load-deflection characteristics of TMAL, CNA and RES ($P > 0.05$).
Conclusion: It appears dry heat sterilization increases stiffness of RES, BETA, CNA and HONE but autoclave sterilization did not have any effect on load-deflection characteristics of most of the β-titanium wires tested, indicating that clinicians who want to provide maximum safety for their patients can autoclave TMAL, RES and CNA before applying them.

Key Words: Beta titanium, orthodontic wire, sterilization

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INTRODUCTION

Sterilization in orthodontics has repeatedly been discussed and emphasized in the dental literature.[1-6] The orthodontic personnel are at a great risk of various contagious diseases and Hepatitis B, Acquired immuno deficiency syndrome (AIDS) and Herpes infections are some of the serious conditions encountered in an orthodontic office.[3,4] Therefore, the Center for Disease Control (CDC) specifies that all instruments which are not expected to penetrate into soft tissue or bone but will certainly contact oral tissues must be sterilized, too.[1] In cases in which barrier techniques are not used, cross-infection between the orthodontic personnel and patients is possible. In addition, since orthodontic clinics have a large number of patients during the day compared to other dental clinics, each clinic requires its own custom-made sterilization processes.[4] Orthodontic wires constitute the most important items in orthodontic clinics. They produce the desired biomechanical forces for tooth movement.[7] These wires are usually marketed sealed in separate bags to avoid cross-contamination. It was shown in a study by Pernier *et al.* that 12% of unused orthodontic wires are not sterile and produce bacterial colonies in a culture. Therefore, the instructions on the packages generally recommended sterilization before use.[8] At present, orthodontic wires are selected in

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different stages of the treatment procedure not only based on wire diameter, but also biomechanical and deactivation properties of wires in order to achieve the best treatment results.[9,10] β-titanium (TMA) wires are alloys of titanium and molybdenum, which were introduced in the early 1979 by Goldberg and Burstone for use in orthodontic treatment.[11] These wires are becoming more popular because of their excellent balance of mechanical properties and absence of nickel, resulting in better tolerance by many patients; some of these mechanical properties include:

1. Lower elastic modulus in comparison to stainless steel
2. High formability
3. Ability of direct welding
4. Good spring-back
5. Low stiffness
6. Low force delivery[11-16]

The limitation of β-Ti wires is their high coefficient of friction. However, some manufacturers have used different methods to solve this problem, including incorporation of a titanium nitride and titanium oxide layer on the wire surface through ion implantation, changing their composition, highly polishing of the surface and increasing the surface smoothness.[7,17-24]

Some previous studies have evaluated the effect of sterilization on wires with various alloy combinations (β-Ti, NiTi, SS),[8,25-28] with contradictory results in relation to β-Ti wires. In addition, after the expiration of patent on β-Ti wires by Ormco (Glendora, California, USA)[20,29,30] various manufacturers produce these wires with different compositions and processing methods, resulting in different mechanical properties and different effects as a result of sterilization processes. Therefore, the clinician needs to have a proper understanding of these characteristics. The aim of the present study was to evaluate the effect of sterilization with dry heat and steam on load-deflection characteristics of β-Ti wires, with different brands.

MATERIALS AND METHODS

In the present study five different types of β-titanium wires with a cross-section of 0.43 × 0.64 mm (0.017 × 0.025 inch) were evaluated [Table 1]. The wires were of the straight type. In cases in which only the preformed arch forms were available their straight posterior segments were used. A total of 30 wire segments from each type were provided; each segment measured 30 mm in length. Then the wires were randomly divided into three groups of 10.

Group I was assigned as the control group. The wire samples in group II were sterilized by dry heat in an oven (12 Bahman Digital Sterilizer, DSL 40, Isfahan, Iran) at 160°C for 1 hour. The wire samples in group III were sterilized by steam in an autoclave (Melag Euroclav, 23 V-S, Berlin, Germany) at 121°C and 15 psi for 15 minutes. The wire samples were left to gradually cool to temperatures near the ambient temperature in the same sterilizers. Both process indicators and test strips were used to ensure the sterilization cycles and processes. Then the samples underwent a three-point load-deflection test in the dry state as described by Miura *et al.*[31] The test was carried out using a Universal mechanical testing machine (Model 1122, Instron Corporation, Canton, MA, USA) using a specially designed setup, consisting of two metallic half-cylindrical structures placed parallel to each other. A single maxillary first premolar bracket (American Orthodontics, Master Series, WIS, USA), with a 0.022 × 0.028-inch slot size with zero angulation and zero torque was bonded on each of the half-cylinders [Figure 1], with a distance of 14 mm between the brackets. The wire sample to be tested was fixed on the brackets using 0.012-inch elastomeric ligatures (Ortho Organizers, Carlsbad, California, USA). The center of each wire was deflected by moving a metallic pole adjusted on the upper head of the testing machine at a crosshead speed of 0.5 mm/min. The load was recorded at 0.1-mm intervals from the inactive position up to 1.5 mm of activation and then returning to the zero point to achieve load-deflection characteristics of

Table 1: β-titanium wires tested in the present study

Code	Wire	Manufacturer	Form
HONE	TMA low friction colored - Honeydew	Ormco Corp, Glendora, California, USA	Archform
TMAL	TMA low friction	Ormco Corp, Glendora, California, USA	Archform
RES	Resolve	GAC International, Inc, Central Islip, NY, USA	Straight wire
BETA	BetaForce	Ortho Technology, Tampa, Florida, USA	Straight wire
CNA	Beta CNA	Ortho Organizers, Carlsbad, California, USA	Straight wire

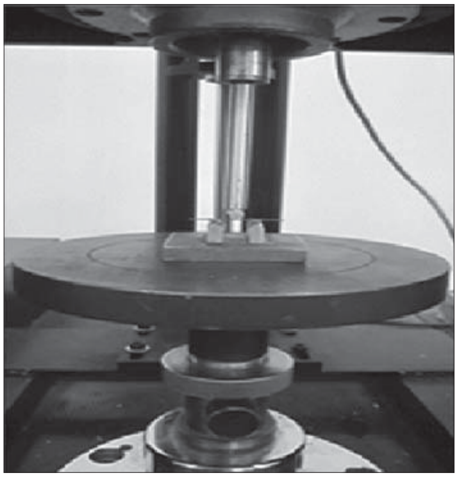

Figure 1: Load-deflection apparatus with the wire in place

each wire. The forces during loading and unloading were registered.

Data was analyzed using repeated measures ANOVA to compare load-deflection properties of the five types of β-Ti wires and determine the changes in characteristics during loading and unloading separately after sterilization of each wire type. Then Scheffé's test was used to determine statistical significance at $P<0.05$. Scheffe is a post-hoc test, done after ANOVA test, to evaluate the differences between each two groups.

RESULTS

Tables 2 and 3 present means and standard deviations of loading and unloading forces of different types of β-Ti wires after 1.5 mm of deflection in the three groups under study at 0.1-mm intervals. Figures 2-6 show load-deflection curves.

Load-deflection characteristics of the five types of β-Ti wires

Repeated measures ANOVA showed that during loading, HONE wire had the least force level ($P < 0.05$) and RES wire had the highest force level. However, there were no statistically significant differences in force levels between RES, CNA and BETA wires ($P > 0.05$). No significant differences were observed in force levels between TMAL and BETA wires ($P > 0.05$). The force levels of RES and CNA wires were significantly higher than that of TMAL wire ($P < 0.05$). During unloading, TMAL and HONE wires exhibited the lowest force levels ($P < 0.05$); although the force of TMAL wire was a little less than that of HONE wire, there were no significant differences between them ($P>0.05$). RES wire exhibited the highest force level, which was significantly higher than those of BETA, TMAL and HONE wires ($P < 0.05$).

Although RES wires exhibited force levels slightly higher than those of CNA wires, there were no significant differences between the two wires ($P > 0.05$). There were no significant differences in force levels between BETA and CNA wires ($P > 0.05$).

Effect of sterilization process on loading and unloading characteristics of β-Ti wires of various brands

Repeated measures ANOVA revealed the following [Figures 2-6]:

BETA wires

Dry heat sterilization group (II) exhibited the highest force levels during loading and unloading ($P < 0.05$). The force levels in the group sterilized by steam (III) were significantly higher than those in the control group (I) during both loading and unloading ($P < 0.05$). The force levels of various groups of BETA wires during loading and unloading were as follows: I < III < II.

RES and CNA wires

The dry heat sterilization group (II) exhibited the highest force levels during loading and unloading ($P < 0.05$). There were more differences between groups I (control) and II in the higher deflection ranges [Figures 3 and 4]. There were no significant differences in force levels between the control (I) and steam sterilization groups during loading and unloading ($P > 0.05$). The force levels of various RES and CNA groups during loading and unloading were as follows: I≈III<II.

HONE wire

During loading, the dry heat sterilization group (II) exhibited the highest force level ($P < 0.05$). There were no significant differences in force levels between the control (I) and steam sterilization (III) groups ($P > 0.05$). During unloading, the steam sterilization group (III) had the highest force levels ($P < 0.05$). There were no significant differences in force levels between the dry heat (II) and control (I) groups ($P > 0.05$). The force levels of different HONE wire groups during loading and unloading had the following relationships, respectively: I≈III<II and I≈II<III.

TMAL wires

There were no significant differences in force levels during loading and unloading between groups I, II and III ($P > 0.05$) (I≈II≈III).

Table 2: Means and standard deviations (SD) for loading forces at 0.1 mm intervals of deflection for wire samples in groups I-III

Loading deflection (mm)	Sterilization	TMAL mean (SD)	HONE mean (SD)	RES mean (SD)	BETA mean (SD)	CNA mean (SD)
0.1	Group I	318 (42)	219 (60)	354 (7)	204 (47)	332 (28)
	Group II	303 (16)	351 (81)	339 (27)	345 (33)	340 (13)
	Group III	299 (23)	252 (67)	346 (32)	335 (21)	335 (9)
0.2	Group I	595 (34)	479 (90)	634 (7)	459 (69)	605 (44)
	Group II	589 (23)	700 (67)	615 (37)	619 (44)	619 (18)
	Group III	579 (31)	542 (66)	634 (42)	603 (31)	609 (16)
0.3	Group I	866 (32)	795 (112)	905 (10)	806 (48)	883 (56)
	Group II	872 (26)	993 (61)	904 (49)	907 (60)	910 (21)
	Group III	850 (37)	840 (47)	904 (52)	884 (38)	891 (16)
0.4	Group I	1134 (39)	1102 (84)	1150 (15)	1093 (43)	1135 (58)
	Group II	1150 (31)	1266 (59)	1172 (52)	1171 (64)	1177 (24)
	Group III	1114 (44)	1120 (40)	1151 (55)	1142 (31)	1142 (18)
0.5	Group I	1389 (34)	1363 (77)	1381 (16)	1338 (46)	1374 (57)
	Group II	1424 (36)	1528 (50)	1431 (52)	1424 (64)	1433 (27)
	Group III	1375 (50)	1384 (42)	1386 (59)	1379 (30)	1380 (21)
0.6	Group I	1627 (34)	1601 (69)	1600 (18)	1576 (27)	1603 (60)
	Group II	1680 (38)	1756 (37)	1685 (52)	1672 (65)	1687 (27)
	Group III	1621 (56)	1629 (44)	1612 (60)	1610 (30)	1610 (26)
0.7	Group I	1833 (41)	1802 (59)	1806 (18)	1789 (23)	1813 (65)
	Group II	1898 (42)	1936 (34)	1922 (52)	1903 (67)	1917 (32)
	Group III	1833 (62)	1836 (44)	1821 (61)	1825 (34)	1822 (29)
0.8	Group I	1998 (49)	1960 (55)	1995 (20)	1982 (25)	2004 (69)
	Group II	2066 (47)	2073 (37)	2144 (52)	2120 (69)	2134 (34)
	Group III	2003 (66)	1997 (47)	2013 (60)	2026 (38)	2017 (32)
0.9	Group I	2125 (53)	2080 (58)	2167 (21)	2155 (29)	2173 (73)
	Group II	2193 (47)	2175 (41)	2345 (52)	2314 (71)	2329 (36)
	Group III	2133 (67)	2118 (48)	2189 (60)	2208 (42)	2188 (36)
1	Group I	2224 (54)	2171 (60)	2316 (21)	2301 (36)	2318 (79)
	Group II	2291 (47)	2253 (45)	2518 (51)	2480 (71)	2497 (38)
	Group III	2233 (66)	2209 (47)	2343 (58)	2362 (43)	2339 (35)
1.1	Group I	2305 (55)	2242 (63)	2443 (21)	2423 (40)	2436 (83)
	Group II	2367 (43)	2313 (47)	2661 (51)	2612 (68)	2633 (42)
	Group III	2309 (65)	2276 (43)	2474 (56)	2491 (43)	2463 (34)
1.2	Group I	2368 (56)	2295 (65)	2544 (21)	2521 (41)	2537 (84)
	Group II	2427 (43)	2360 (48)	2777 (49)	2713 (64)	2740 (43)
	Group III	2373 (65)	2328 (41)	2581 (52)	2595 (45)	2566 (34)
1.3	Group I	2421 (57)	2339 (68)	2626 (22)	2602 (43)	2619 (84)
	Group II	2478 (40)	2398 (47)	2866 (48)	2783 (57)	2822 (43)
	Group III	2427 (66)	2368 (40)	2673 (50)	2687 (49)	2652 (34)
1.4	Group I	2471 (60)	2373 (72)	2697 (25)	2668 (44)	2692 (80)
	Group II	2523 (41)	2432 (48)	2928 (52)	2838 (53)	2885 (47)
	Group III	2475 (69)	2405 (40)	2751 (50)	2769 (55)	2726 (34)
1.5	Group I	2507 (62)	2392 (76)	2739 (29)	2710 (49)	2740 (79)
	Group II	2556 (44)	2454 (48)	2958 (54)	2863 (46)	2928 (54)
	Group III	2511 (71)	2424 (41)	2795 (51)	2822 (58)	2782 (37)

According to hysteresis evaluation (energy loss upon unloading) of wires before and after sterilization showed that only sterilization with dry heat resulted in an increase in hysteresis of TMAL and HONE wires; however, autoclave sterilization did not have any effect on hysteresis of the wires under study.

DISCUSSION

β-Ti wires have gained great popularity in orthodontics due to their favorable nature to tooth and supporting tissues.[19] Multi-stage processing of orthodontic wires by manufacturers has a significant influence on their

Table 3: Means and standard deviations (SD) for unloading forces at 0.1 mm intervals of deflection for wire specimens in groups I-III

Unloading deflection (mm)	Sterilization	TMAL mean (SD)	HONE mean (SD)	RES mean (SD)	BETA mean (SD)	CNA mean (SD)
1.4	Group I	1924 (58)	1931 (71)	2123 (41)	2098 (10)	2083 (70)
	Group II	1998 (58)	1967 (44)	2306 (41)	2249 (48)	2204 (31)
	Group III	1917 (30)	1996 (49)	2099 (83)	2080 (47)	2058 (45)
1.3	Group I	1652 (46)	1668 (58)	1859 (35)	1838 (15)	1834 (63)
	Group II	1698 (46)	1685 (39)	2045 (37)	1983 (35)	1967 (25)
	Group III	1641 (22)	1726 (31)	1840 (62)	1827 (35)	1822 (36)
1.2	Group I	1406 (35)	1426 (52)	1651 (30)	1624 (16)	1629 (61)
	Group II	1434 (37)	1425 (36)	1829 (33)	1777 (33)	1766 (23)
	Group III	1398 (16)	1486 (25)	1641 (51)	1630 (28)	1627 (31)
1.1	Group I	1175 (30)	1193 (49)	1465 (26)	1431 (14)	1440 (59)
	Group II	1185 (33)	1176 (34)	1629 (26)	1588 (30)	1577 (20)
	Group III	1167 (13)	1255 (26)	1461 (44)	1453 (22)	1447 (27)
1	Group I	949 (27)	965 (45)	1289 (23)	1247 (12)	1260 (54)
	Group II	940 (32)	929 (33)	1437 (21)	1403 (27)	1391 (18)
	Group III	940 (13)	1027 (32)	1289 (38)	1283 (18)	1273 (23)
0.9	Group I	724 (27)	739 (42)	1116 (21)	1067 (12)	1083 (49)
	Group II	698 (31)	686 (31)	1247 (17)	1218 (24)	1207 (18)
	Group III	716 (16)	801 (40)	1120 (34)	1115 (17)	1102 (21)
0.8	Group I	501 (27)	515 (40)	945 (19)	889 (13)	908 (46)
	Group II	458 (31)	446 (31)	1058 (15)	1033 (24)	1021 (19)
	Group III	493 (19)	578 (47)	951 (30)	947 (15)	932 (19)
0.7	Group I	280 (28)	296 (40)	773 (18)	710 (16)	735 (39)
	Group II	222 (30)	211 (31)	867 (14)	846 (25)	831 (20)
	Group III	270 (23)	357 (54)	784 (26)	779 (13)	761 (18)
0.6	Group I	62 (28)	82 (39)	600 (16)	528 (21)	559 (33)
	Group II	10 (16)	7 (11)	671 (14)	655 (28)	637 (24)
	Group III	50 (24)	143 (58)	613 (23)	609 (12)	589 (17)
0.5	Group I	0	0	424 (15)	351 (20)	383 (27)
	Group II	0	0	471 (15)	456 (33)	438 (26)
	Group III	0	0	438 (20)	435 (11)	413 (17)
0.4	Group I	0	0	245 (15)	167 (19)	204 (19)
	Group II	0	0	269 (14)	253 (36)	233 (28)
	Group III	0	0	258 (17)	254 (10)	234 (16)

mechanical properties.[32,33]

High autoclave or dry heat sterilizer temperatures, too, might influence the mechanical properties of wires. Therefore, it is important for the manufacturers to evaluate the effect of sterilization procedures on β-Ti wires. Heat sterilization techniques were selected in the present study because they are the most popular type of sterilization technique used in dental offices; in addition, it is the most typical method recommended until now.[6,34]

The load-deflection properties are significant parameters in determining the biologic nature of tooth movement.[10] A modified version of the three-point bending test was used in the present study to evaluate load-deflection properties of orthodontic wires. This technique provides a simple model by determining the nature of forces applied during orthodontic treatment and closely simulates clinical situations.[31] In the clinic, when a wire undergoes deflection to be placed within a bracket on a malaligned tooth, in fact, it undergoes loading. When a wire is inclined to return to its original shape, unloading takes place, which provides the necessary force to elicit a biologic tissue response, resulting in the alignment of teeth.[35] However, laboratory tests do not necessarily reflect the clinical situations; rather, they provide a basis for the comparison of various brands of wires.[16]

Of the five brands of wires under study [Tables 2 and 3], the wires manufactured by Ormco (TMAL and HONE) exhibited the lowest force during unloading, with TMAL forces being higher than those of HONE

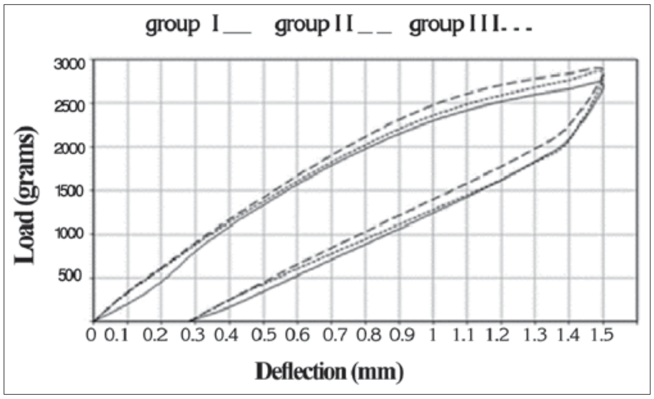

Figure 2: Load-deflection graph of BETA wires in the control group and after sterilization with dry and moist heat

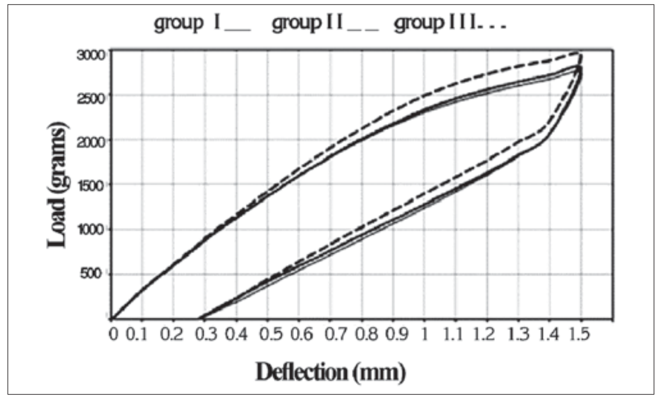

Figure 3: Load-deflection graph of CNA wires in the control group and after sterilization with dry and moist heat

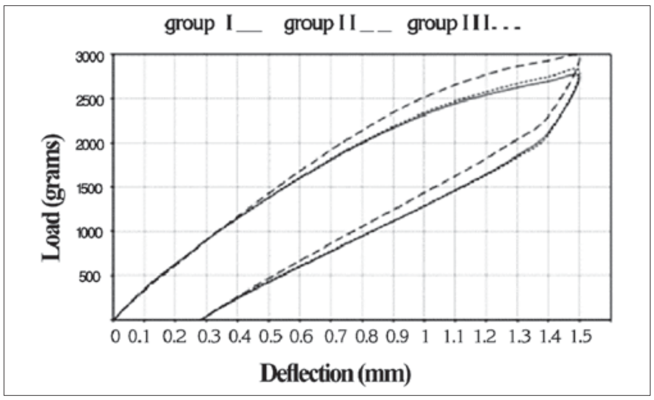

Figure 4: Load-deflection graph of RES wires in the control group and after sterilization with dry and moist heat

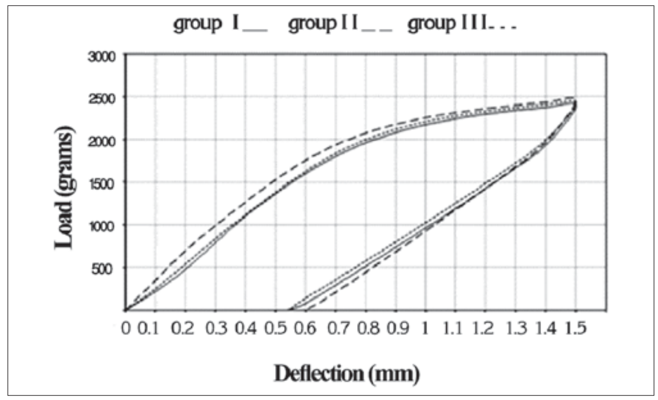

Figure 5: Load-deflection graph of HONE wires in the control group and after sterilization with dry and moist heat

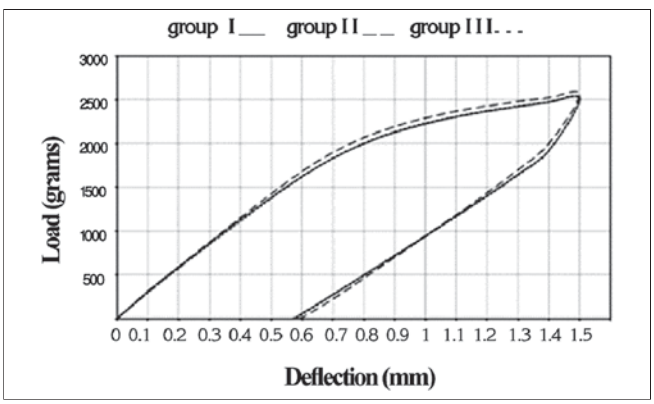

Figure 6: Load-deflection graph of TMAL wires in the control group and after sterilization with dry and moist heat

during loading, statically equal to those of BETA wires. Therefore, HONE wires, compared to the other types tested, are more easily engaged in the brackets of malaligned teeth due to lower force levels needed to deflect.

RES and CNA wires required higher force levels for deflection; therefore, these wires exhibited greater stiffness in comparison to TMAL and HONE wires, which might be attributed to differences in composition and processing of the alloys used in the manufacture of each of these orthodontic wires. Given the curves and steepness of load-deflection graphs of the control wires in the present study [Figures 2-6], it appears RES, BETA and CNA wires have different behaviors compared to the two products from the Ormco company (TMAL and HONE). These results are supported by those of Kusy *et al.,*[29] who reported that the same wire manufacturer due to similar composition and surface roughness could have manufactured the β-Ti new products of RES, BETA III and CNA. The original β-Ti alloy from the Ormco Company could have been manufactured with the same characteristics.

The results of the present study showed that dry heat sterilization significantly increases force levels during loading and unloading of CNA, BETA and RES and loading of HONE wires, making them stiffer. As indicated by the increased slope of the graphs [Figures 2-5] dry heat sterilization influences the clinical performance of CNA, RES, BETA and HONE wires. It also results in increased force delivery by CNA, RES and BETA to teeth. The differences in the effect of sterilization with dry heat and steam might be attributed to the use of longer times and higher temperatures in the sterilization process by dry heat. However, sterilization with dry heat did not result in significant changes in force levels during loading and unloading of TMAL wires [Figure 6]. Previous studies on the effect of dry heat sterilization on β-Ti wires have evaluated only TMA wires (Ormco, Glendora, California, USA) with a size of 0.016 inch. Smith *et al.* reported that use of dry heat sterilization with a temperature of 375°F (191°C) for 10 minutes on TMA archform wires (Ormco, Glendora, California, USA) which had already been used clinically did not exert any influence on tensile and load-deflection test results of the wires.[25] The results of the present study with TMAL wires are consistent with the results of a study by Smith *et al.* with TMA wires.

Stagers *et al.* evaluated the effect of dry heat sterilization at 375°F for 20 minutes on TMA wires (Ormco, Glendora, California, USA) and reported a significant increase in the tensile strength of wires.[26]

In addition to the type and size of the wires, other factors, which might have resulted in differences between the results of the present study and other studies, mentioned above might be the differences in the sterilization protocols and the type of the mechanical tests applied.

The results of the present study did not show any effect of steam sterilization (autoclave) [Figures 2-6] on load-deflection characteristics of the majority of β-Ti wires tested; however, it increased force levels during loading and unloading of BETA and unloading of HONE wires, which is reflected by an increased slope of loading and unloading of BETA and unloading of HONE wires [Figures 2 and 5]. Therefore, these wires will deliver greater forces to teeth after sterilization in an autoclave.

Regarding the low force levels of TMAL wire, especially during unloading both in the control group and after sterilization, it appears ion implantation process is only related to surface characteristics and a decrease in friction, with no detrimental effects on load-deflection characteristics of the wire even after sterilization.

The different effects of sterilization on HONE and TMAL wires might be attributed to differences in the type and concentration of ions or other factors during the manufacturing processes of these wires.[23,24] It is suggested that clinicians sterilize TMAL, RES and CNA wires in an autoclave before using them without any worries because their favorable load characteristics will not undergo any changes after sterilization, which is consistent with the results of a study carried out by Pernier *et al.* on the effect of autoclave sterilization at 134°C or 274°F for 18 minutes on TMA, TMAL and RES wires. They reported no differences in load-displacement curves after sterilization of any wire tested.[8]

Staggers *et al.* reported no effect of autoclave sterilization (250°F for 20 minutes) on tensile strength of TMA wires.[26]

In addition, a study by Smith *et al.* did not show any perceptible clinical differences between new wires and clinically used wires, which are later, sterilized in an autoclave (274°F for 10 minutes).[25]

CONCLUSIONS

1. The results of the present study showed differences in force levels during loading and unloading between the five brands of β-Ti wires under study after 1.5 mm of deflection; RES, CNA and BETA wires exhibited different force deflection behaviors in comparison with the two products of Ormco Company (TMAL and HONE).
2. There are different changes in load-deflection characteristics of various β-Ti wires after sterilization with dry heat and heated steam.
3. The clinicians who want to provide maximum safety for their patients can sterilize RES, TMAL and CNA wires in an autoclave without any worries before placing them in the oral cavity.

However, further *in vivo* studies are required to substantiate the results of the present study.

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