Original Article

Effect of Saliva on Load-Deflection Characteristics of Superelastic Nickel-Titanium Orthodontic Wires

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Abstract

Objective: Most published results about the characteristics of NiTi wires are based on the mechanical laboratory tests on the as-received wires.The purpose of this study was to investigate the effect of saliva on load-deflection characteristics of superelastic NiTi wires.

Materials and Methods: In this experimental study, 15 wires of three kinds of superelastic NiTi wires (Sentalloy, Force I and Truflex) were prepared. Five specimens of each wire were tested in the as-received condition (T0) to provide baseline information and the remaining wires were divided into two groups of five. Half of them were kept inside artificial saliva for one month (T1), while the others were kept in air (T2). After 30 days, three-point bending test was done in a dental arch model and data from selected points on the unloading phase of the generated graphs were used for statistical analysis.

Results: Force I and Truflex showed significantly greater force than Sentalloy. The load values of Truflex and Force I after one month exposed to artificial saliva (T1) decreased significantly, but Sentalloy was not affected significantly. The plateau gap values were not considerably different among T0, T1 and T2.

Conclusion: Saliva decreased the load of Force I and Truflex significantly, but it did not have a statistically significant effect on Sentalloy.

Key Words: Artificial Saliva; Superelastic NiTi Wires; Three-Point Bending

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INTRODUCTION

Nickel-titanium (NiTi) orthodontic arch wires were first introduced to the orthodontics by Andreasen and Hilleman in 1971[1]. NiTi orthodontic wires exhibit mechanical properties such as low stiffness, high springback, shape

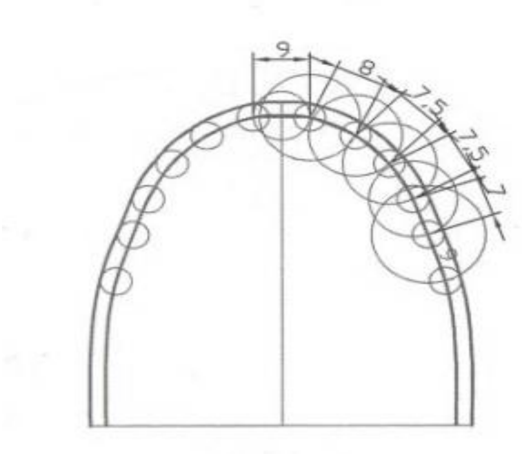

Fig 1. Locations of the teeth; each circle represents a tooth, which is located according to the mentioned distances and set with the precise angle

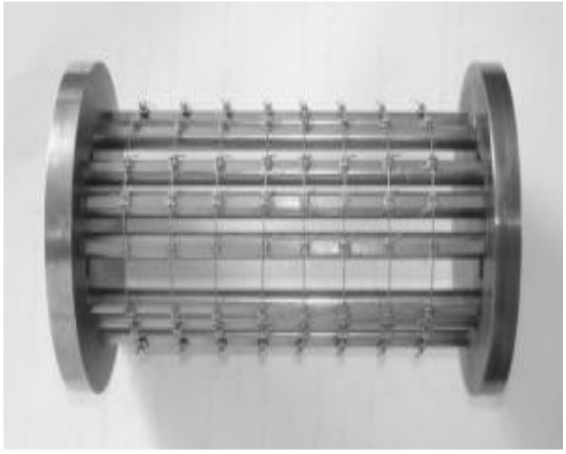

Fig 2. Engaged wires on the phantom model

memory and superelastic properties [2,3]. These wires are used as initial alignment wires in orthodontic treatment widely.

There are three types of nickel-titanium alloy; the first type (original) has a stabilized martensitic structure, which is consisted of 55% Nickel and 45% Titanium [4]. It is produced by the process of cold working. Thus, the effect of thermo-dynamical memory is suppressed and the possibility of changing the structure by varying temperature is eliminated [5].

This wire is springy and there is a linear relation between the increase in the deactivation phase and power reduction of the wires.

The superelastic nickel-titanium (the second type of NiTi alloys) is a perfected kind of original stabilized alloy.

When it is placed under load, it undergoes phase transformation from an austenitic to a martensitic crystal structure and when unloaded, it goes back to the previous structure. Superelasticity is a qualitative mechanical feature, which is characterized by the load-deflection curve, in a way that on this curve an area of plateau is observed during the unloading process. This means that the wire applies an equal pressure on the teeth for most part of the deflection [6].

The third type of NiTi alloys (thermoelastic alloys) has the effect of shape memory depending on temperature. The first generation of NiTi wires also have shape memory, but their Transition Temperature Range (TTRs) made them impractical to use in orthodontics, while the thermoelastic NiTi wires or heat activated wires have a useful shape memory for clinical use in a way that the alloy is soft at room temperature and the wires are easily ligated between the highly malposed teeth. When the wire is warmed up more than its TTR, the ratio of austenite in the alloy along with the stiffness are increased. Therefore, the wire transforms to its previous shape [7].

According to our data, there is little information about the effect of saliva on the mechanical characteristics of NiTi wires and most published results about load-deflection properties of NiTi wires are limited to the wires in the as-received condition [4,7,8], while clinicians set arch wires under different stresses and strains in the corrosive environment of the mouth for a few months. Harris et al. demonstrated that saliva affects some mechanical properties of Nitinol such as ultimate stress, modulus of elasticity and 0.2% yield strength [9]. In addition, Ramazanzadeh et al. concluded that NiTi wires deflected for 2 months in a simulated

Fig 3. Universal testing machine

Fig 4. Three-point bending test

oral environment had lower force than control wires [10]. Although there are a lot of studies about the effect of saliva on corrosion behavior and surface characteristics of nickel-titanium orthodontic arch wires [11-13], the effect of saliva on mechanical properties of NiTi wires is not so clear. The purpose of this study was to evaluate the load-deflection properties ofsuperelastic NiTi wires in the as-received condition and after one month of storage in artificial saliva.

MATERIALS AND METHODS

In this experimental study, the load deflection characteristics of three kinds of 0.016 superelastic NiTi wires were studied: Sentalloy (GAC) 355 Knickerbocker Avenue, Bohemia, NY USA, Force I (American Orthodontics) and Truflex (Orthotechnology). In order to study the load deflection of these wires, the three-point bending test was used. To simulate clinical condition a phantom model was designed similar to the dental arch in the mouth.

Table 1. Load Values (N) During Unloading at 2 and 3 mm Deflections

Deflection (mm)	Force I						Truflex						Sentalloy					
	T0		T1		T2		T0		T1		T2		T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2	1.7580	0.2574	1.1090	0.1739	1.6147	0.1433	1.4520	0.0471	0.9760	0.2558	1.3730	0.1029	0.5900	0.0943	0.5463	0.2296	0.6240	0.0649
3	1.8325	0.2046	1.5550	0.2050	1.8950	0.1220	1.5600	0.0895	1.0450	0.0578	1.4920	0.1440	0.6888	0.0641	0.6240	0.0504	0.6430	0.1549

T0: as-received wires, T1: wires were inside saliva for 1 month, T2: wires were outside saliva for 1 month

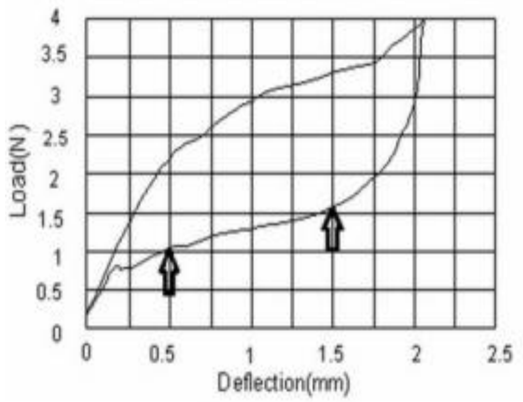

Fig 5. Selected points at 2 mm load-deflection test

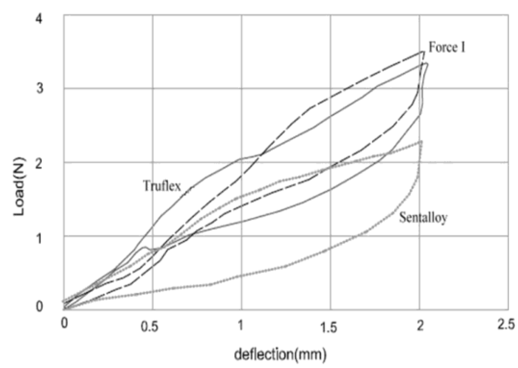

Fig 6. Load-deflection graph for NiTi wires at 2 mm deflection test

To do so, the ideal maxillary arch form of GAC template was used and to determine the distances between the teeth, the typical distances between a man's permanent maxillary teeth were considered [14]. Using Auto CAD software (Autodesk 2002), the exact location of the teeth was determined (Fig 1). To make the designed model, first two discs made from stainless steel, with a diameter of 80 mm and a thickness of 10 mm were prepared. Then some steel bars with a diameter of 5 mm and a height of 200 mm (each one representing a tooth) were welded between the two discs on specific spots, but the bars of the upper right lateral and upper left canine were not welded and we could remove them in order to do the three-point bending test on the same model. Then, eight sets of standard maxillary GAC twin brackets were stabilized on the bars by super glue. The length between the two sets was 1.5 cm.

Similar molar tubes were glued over the locations on the molar teeth. The slot size of all brackets and tubes were 0.018 × 0.025 inch. In order to install all brackets on the same vertical level, an arch wire (0.018 × 0.025 inch) was used as a guide. In order to have a solid connection between the brackets and bars, all the brackets were welded to the bars by laser. Finally each NiTi wire was engaged inside a set of brackets by a ligature wire (Fig 2).

For this purpose, fifteen wires of each kind were prepared; five of them were tested immediately to provide baseline information on the as-received wire (T0) and the rest were divided into two groups of five. To evaluate the effect of saliva, half of them were put inside artificial saliva (T1) and the other half outside (T2) for one month.

Modified Fusayama artificial saliva [15,16] was used, which consisted of NaCl (400 mg/L), KCl (400 mg/L), $CaCl_2.2H_2O$ (795 mg/L), $NaH_2PO_4.H_2O$ (690 mg/L), KSCN (300 mg/L), $Na_2S.9H_2O$ (5 mg/L) and Urea (1000 mg/L). The solution was adjusted to a PH of 7 using sodium hydroxide.

After one month, the three-point bending test was done on all the samples. Therefore, by pulling out the mobile bars the model was prepared for the three-point bending test. The apparatus of universal testing machine (Zwick 050, Germany) was used to perform the test (Fig 3). Of course in order to do the three-point bending on this model, a base (fixture) was needed to keep the model steady on the apparatus. Therefore, a special base for the model was designed by AutoCAD and made by SPK steel. Then by means of one load-cell (20 Newton) with a 1.6 mm-diameter polished steel rod and the speed of 2 mm/min in the buccolingual direction, the wire was under the process of loading and unloading (Fig 4). The

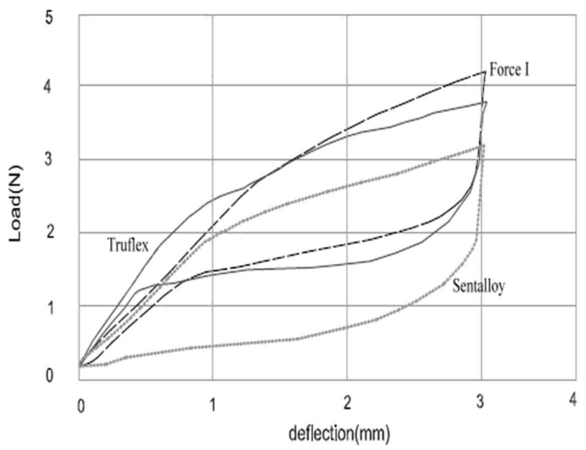

Fig 7. Load-deflection graph for NiTi wires at 3 mm deflection test

amount of deflection at the region of right lateral and left canine was 2mm and 3mm, respectively. The wires of the control group were also taken under three-point bending test so they could be used as an indicator to compare the results of the test. A computer connected to the apparatus drew the load deflection curve of each test.In order to study the reactions of wires on each curve, the amount of force on two points of unloading phase were registered.

The points were chosen in a way to show a standardized portion of the unloading phase plateau in the load deflection curve [7]. Therefore, the selected points on the unloading phase were 0.5mm less than the maximum deflection on each bending and the bending point of 1mm (Fig 5).

In order to study the amount of force, the average between these two points on the curve was calculated and used for the average load of each wire. The plateau gap on each curve was the average load difference between the values of those points. This shows the measure of the unloading plateau over a standardized deflection distance.

To investigate the effect of the type of wire and saliva on load and plateau gaps, two-way analysis of variance (ANOVA) tests were used and one-way ANOVA was done for other factors. SPSS 11.5 software (Chicago, Illinois) was used to do all the statistical operations considering a meaningful level less than 0.05 after Boneferrony adjustment.

RESULT

Table 1 shows mean load values at different deflections during unloading for the three wires in the as-received condition (T0) after one month storage in artificial saliva (T1) and storage in air (T2). The most obvious differences are observed between Sentalloy and the other wire types. Generally, the maximum force among the three 0.016 inch wires was exerted by Force I and the minimum force was exerted by Sentalloy. The results showed that in T0, T1and T2 groups at all deflections, Sentalloy had a significantly lower force than Force I and Truflex ($p<0.05$).

The load-deflection curves for the as-received wires areshown in figures 6 and 7. Each curve was obtained by an average of five tests for only one type of wire.

The load-deflection curves had super-elasticity feature, but on these curves the area of plateau had different slopes, force and length depending on the type of wire, the amount of bending and maintenance condition of the wires during the test.

Comparison of load values of T0 and T2 specimens showed no considerable difference between these groups. One month immersion of wires in artificial saliva significantly affected load values of Force I and Truflex and T1 specimens of these two wires were generally associated with significantly lower forces compared with control (T0) specimens, but load values of T1 Sentalloy were not significantly different from those of T0 specimens.

Table II shows the average of plateau gap values at different deflections for the three wires at T0, T1 and T2. Comparing plateau gap values among the different three wires showed no significant difference. In addition, the plateau gap values of T0 wires were not significantly different from T1 and T2 specimens.

DISCUSSION

Dental implant The main goal of the present study was to investigate the effect of saliva on load-deflection characteristics of three superelastic NiTi wires. The results showed that the load values of Truflex and Force I after one month storage in artificial saliva decrease significantly, but Sentalloy is not affected significantly. In addition, comparison between load-deflection curves (Fig 6,7) shows that in different deflections, all three wires reacted the same way, but the load values of Sentalloy were lower than the load of Force I and Truflex and this difference was about 50-100 grams that is clinically significant. Comparison of plateau gap values in all wires indicates that there was no significant statistical difference among Sentalloy, Truflex and Force I and all wires were almost similar when it came to the plateau of unloading phase. This fact shows that the stability of the force produced by all types of NiTi wires is almost the same and saliva does not affect it.

Since the results of the studies like those of Wilkinson [7] and Parvizi [4] showed that the load-deflection performance of wires depends on the design of the test model, in this study a special dental arch model was made to simulate clinical condition and three-point bending test was carried out on this model. Besides, the results of Oltjen's study [17] indicated that wires, which were engaged in brackets during bending tests show more stiffness than those that were set on two pillars without any attachment. So in the present study, installing brackets on the model helped us to get closer to the clinical condition.

The ligation method of the wire to brackets is another important factor in increasing the force of a wire.

Kasuya [18] showed that ligating the NiTi wires to the brackets causes an increase in the wire force and brings about a change along the load-deflection curve. The lowest level of force belonged to self-ligating brackets and after that ligation by stainless steel ligature. The elastomeric ligatures also caused elimination of the super-elasticity of NiTi wires and the load-deflection curve of the NiTi wires became linear similar to steel wires.

Table 2. Plateau Gap Values (N) During Unloading at 2 and 3 mm Deflections

Deflection (mm)	Force I						Truflex						Sentalloy					
	T0		T1		T2		T0		T1		T2		T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	0.6060	0.0998	0.6260	0.1128	0.6460	0.1083	0.5400	0.1453	0.5360	0.1214	0.6020	0.1777	0.6160	0.0935	0.5900	0.1302	0.6475	0.0943

T0: as-received wires, T1: wires were inside saliva for 1 month, T2: wires were outside saliva for 1 month

According to the results and considering the frequent use of steel ligature wires in clinic, in this study the NiTi wires were engaged to brackets by ligature wires.

Corrosion behavior and surface characteristics of nickel-titanium orthodontic arch wires were evaluated in many studies [11-13] and the effect of saliva on their chemical properties is nearly clear. However, the effect of saliva on mechanical properties of NiTi wires is under debate. Harris et al. [9] put 0.016 Nitinol wires under different amount of deflections (0 to 4 mm in a 10 mm span) across time (1, 2 and 4 months) in artificial saliva at various levels of acidity. The results showed that storage of Nitinol in a simulated oral environment compared with control wires, decreases ultimate stress, modulus of elasticity and 0.2% yield strength. A previous study demonstrated that immersion of NiTi wires in a simulated oral environment in deflected state significantly degraded their superelastic properties and these wires were generally associated with significantly lower forces than control wires in deflections less than 2 mm [10]. Our results showed that the load value of as-received Sentalloy wire is 0.68 N and it was similar to the result of Tonner and Waters (0.61 N) [19].

The optimum force levels for orthodontic tooth movement should be just high enough to move teeth without harming them or the periodontium. Studies have shown that light continuous forces permit an efficient tooth movement with less damage to the teeth or periodontium [20] and maximum patient comfort [21]. Of course determining the precise amount of such ideal force is difficult and it depends on many factors including the size of the tooth and the type of movement [22].

Walters stated that by installing a primary aligning arch wire, the first reaction of the tooth to the applied force is the tipping motion [23]. Groves and Burstone observed that if the force is 50-70 g, an optimum tipping motion occurs [24]. In another study it has been mentioned that the optimal force required for tipping is about 35-60 g [6]. The force exceeding 70 g causes periodontal ligament hyalinization and subsequently a delay in tooth movement [25].

The results of this in vitro study showed that there are a few tested wires that have optimal load. In most cases, the average of load values for Force I and Truflex wires are more than physiological load, ranging from 100 g to 200 g. The load of Sentalloy was within the physiological load limit, usually with a value of 50-70 g. Since the load of super-elastic wires is applied continuously, consistently and with little change within certain time, if the load is too much the periodontal ligament will not have the opportunity to restore itself. Further studies are needed to determine the amount of optimal force in clinical conditions.

CONCLUSION

1. In all situations (as-received wires, after one month storage in saliva and in air) the load values of Sentalloy were lower than Truflex and Force I significantly.
2. Saliva decreased the load of Force I and Truflex significantly, but it did not have a statistically significant effect on Sentalloy.
3. In most cases, the average load for Force I and Truflex wires was more than physiological load, while the load of Sentalloy was within the physiological load limit.

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