

# The effect of ligation on the load–deflection characteristics of nickel–titanium orthodontic wire

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**SUMMARY** This study examined the effect of ligation on the load–deflection characteristics of nickel–titanium (NiTi) orthodontic wire. A modified three-point bending system was used for bending the NiTi round wire, which was inserted and ligated in the slots of three brackets, one of which was bonded to each of the three bender rods. Three different ligation methods, stainless steel ligature (SSL), slot lid (SL), and elastomeric ligature (EL), were employed, as well as a control with neither bracket nor ligation (NBL). The tests were repeated five times under each condition. Comparisons were made of load–deflection curve, load at maximum deflection of 2000  $\mu\text{m}$ , and load at a deflection of 1500  $\mu\text{m}$  during unloading. Analysis of Variance (ANOVA) and Dunnett's test were conducted to determine method difference ( $\alpha=0.05$ ). The interaction between deflection and ligation was tested, using repeated-measures ANOVA ( $\alpha=0.05$ ).

The load values of the ligation groups were two to three times greater than the NBL group at a deflection of 1500  $\mu\text{m}$  during unloading: 4.37 N for EL, 3.90 N for SSL, 3.02 N for SL, and 1.49 N for NBL ( $P<0.01$ ). For the EL, a plateau region disappeared in the unloading curve. SL showed the smallest load. The ligation of the bracket wire may make NiTi wire exhibit a significantly heavier load than that traditionally expected. NiTi wire exhibited the majority of its true superelasticity with SL, whereas EL may act as a restraint on its superelasticity.

## Introduction

Today it has become commonplace for orthodontists to use nickel–titanium (NiTi) archwires, at least in the initial stage of treatment for levelling and aligning. Andreasen and Morrow (1978) first described the usefulness of a NiTi alloy wire called 'Nitinol'. The advancement of industrial technology has led to the progress of orthodontic NiTi wires from work hardening to superelastic types. This would not have been possible without research seeking improvement in superelasticity and shape-memory effect (Okamoto, 1987; Kusy, 1997; Otsubo, 1994a,b). The present worldwide use of NiTi wire in orthodontic practice provides strong clinical evidence that the mechanical properties of NiTi wire are advantageous for efficient tooth movement.

However, it is well known that the efficiency of tooth movement in the levelling stage can be adversely affected by friction generated between the wire and the bracket, Nakada or the ligation system (Okamoto, 1987; Noda and Soma, 1993; Noda *et al.*, 1993; Otsubo, 1994a,b; Nakada *et al.*, 2001; Hain *et al.*, 2003; Moore *et al.*, 2004). Various self-ligating brackets advocated as 'low friction' or 'friction free' have been developed and marketed. The widely accepted merit of these self-ligating brackets is that their use can lead not only to a reduction of chair time but also to less friction. The latter will facilitate more effective utilization of light forces while making use of the superelasticity and shape-memory effect of the NiTi wire (Damon, 1998; Kapur *et al.*, 1998; Griffiths *et al.*, 2005; Henao and Kusy, 2005; Tecco *et al.*, 2005).

Many studies have been conducted concerning friction between the archwire and bracket (Noda and Soma, 1993; Noda *et al.*, 1993; Damon, 1998; Kapur *et al.*, 1998; Nakada *et al.*, 2001; Hain *et al.*, 2003; Moore *et al.*, 2004; Griffiths *et al.*, 2005; Henao and Kusy, 2005; Tecco *et al.*, 2005). No research has, however, been published on how the superelasticity of the NiTi archwire is affected by the ligation system.

The mechanical properties of an orthodontic wire can be described in two ways: the intrinsic or true properties, which concern the real nature of the wire itself, and the effective properties, which concern the nature of the wire that is actually exhibited during treatment, after the wire experiences friction with the bracket or the ligation system, the intraoral temperature, and its transition, etc.

The purpose of the present study was to examine the effect of ligation on the load–deflection characteristics of NiTi orthodontic wire using a modified three-point bending system capable of allowing bracket bonding and wire ligation.

## Materials and methods

A modified three-point bending system (Nagasaka *et al.*, 2006; Figure 1) capable of digitally predetermining the bending speed and the amount of movement or deflection was used for bending the specimen wire. With this system, the wire is bent between a rod connected to a load cell and two rods fixed in a linear gauge. The load arising is

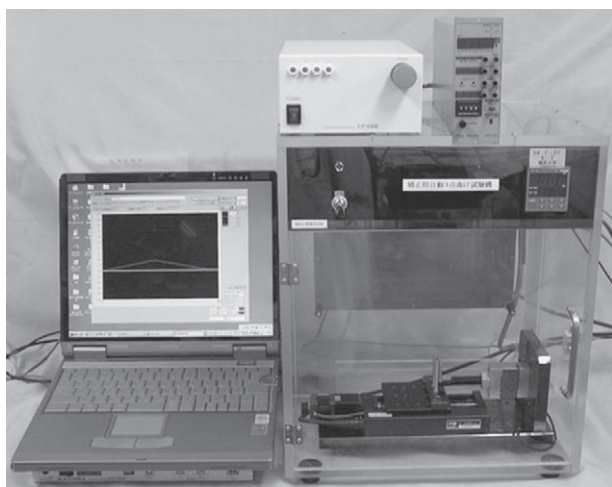
detected as strain by a compression load cell. This strain is converted to voltage by means of a dynamic strain amplifier and further converted from an analogue to digital signal by a sensor interface prior to computer analysis.

In the present experiment, the wire was inserted and ligated in the slots of three brackets, one of which was bonded to each of the three bender rods. These brackets were arranged to all face in the same direction, as would be the case in the clinical situation (Figure 2b–d). The control, however, was set up with neither bracket nor ligation (NBL) and, in this case, was held between the outer rods and the central rod as shown in Figure 2a. Prior to testing, the inter-bender rod distance was fixed at 7 mm.

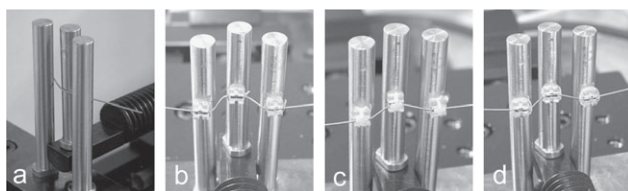
The maximum deflection was set to 2000  $\mu\text{m}$  to partially reflect a clinical situation where a NiTi archwire would be used for aligning mildly crowded anterior teeth.

### Materials

Three orthodontic brackets were bonded to three vertically set up bender rods, one for each, with a dental adhesive resin, Superbond® (Sunmedical Co., Ltd, Shiga, Japan) all at the same level (Figure 2). The brackets utilized were pre-adjusted for lower incisor use [Clear Bracket® (Dentsply-Sankin, Tokyo, Japan)] with a slot width of 0.022 inches (0.56 mm).



**Figure 1** Overall view of the modified three-point bending system used in the present study.



**Figure 2** Bending at a maximum deflection of 2000  $\mu\text{m}$  for four different methods; (a) no bracket-and-ligation, (b) stainless steel ligature, (c) slot lid, and (d) elastomeric ligature.

The specimen wires were cut in lengths of 30 mm from the straight, posterior segments of preformed, 0.016-inch NiTi archwires (Ormco, Orange, California, USA).

For ligation, the following three different methods were used to engage the specimen wire into the bracket slot, to at least partially reflect a clinical situation (Figure 2b–d):

- b. Stainless steel ligature (SSL) of 0.010 inches (0.25 mm) diameter (Ortho Organizers, Carlsbad, California, USA)
- c. Slot lid (SL; Clear Snap®, Dentsply-Sankin)
- d. Elastomeric ligature (EL; TP Orthodontics, La Porte, Indiana, USA).

### Measurement

For each ligation method, a bending cycle comprising loading and unloading was repeated five times at a speed of 10  $\mu\text{m}/\text{seconds}$  for a maximum deflection of 2000  $\mu\text{m}$  using a new specimen of wire on each occasion. To eliminate interpersonal variation in ligation procedure, all ligations were carried out by the same orthodontist who was well-practiced in the procedure. In addition, to minimize intrapersonal variation, the following ligation procedures were used for each ligation method.

1. A pair of mosquito forceps was used to cap the bracket slot with the SL.
2. A gun-type elastic shooter (Straight Shooter®, TP Orthodontics) was used to put on the EL around the bracket wings.
3. The ligature tying pliers were always turned five times to carefully ligate the SSL by generating only a relatively light binding force. This was to ensure that the ligation procedure-deriving force would be small enough not to be detected by the load cell, as this can pick up and show force greater than 0.1 N on the monitor screen.

In addition, in order to form a control group of data, five round-trip bendings were conducted at the same speed, and for the same amount of deflection, this time without any bracket bonded and therefore with no ligation.

The atmospheric temperature for the experiment was set at 37.0°C to reflect that of the oral environment, but otherwise the atmospheric conditions were left the same as those of the laboratory. Comparisons were made in load–deflection curve, load at maximum deflection of 2000  $\mu\text{m}$ , and load at a deflection of 1500  $\mu\text{m}$  during unloading. Digital data on load–deflection relationships were simultaneously collected for comparative evaluation. For statistical evaluation, differences among the three ligation methods were tested by comparing the mean values with ANOVA ( $\alpha=0.05$ ; Windows Release 11.5.1, SPSS Inc., Chicago Illinois, USA). Additionally, Tukey's test was used to statistically identify group difference ( $\alpha=0.05$ ) and Dunnett's test was used to compare each of the three ligation methods with the control ( $\alpha=0.05$ ). Repeated-measures ANOVA was also used to assess the

interaction between the two amounts of deflection and the three modes of ligation ( $\alpha=0.05$ ).

## Result

Figure 3 shows load–deflection curves for NBL, SSL, SL, and EL. The wire in the NBL exhibited a so-called typical NiTi curve containing an unloading plateau range of approximately 1.5 N (Figure 3a). Apparent unloading plateaus were also exhibited for both SSL and SL (Figure 3b,c), though their force levels differed by about 1 N, being approximately 3.5–4 and 2.5–3 N, respectively. The unloading curve for the EL was drawn linearly (Figure 3d), containing no plateau range. Table 1 shows load values at the maximum deflection of 2000  $\mu\text{m}$  for the four different ligation systems, including the NBL. The systems listed in descending order of load magnitude at 2000  $\mu\text{m}$  deflection were SSL, EL, SL, and NBL ( $P<0.01$ ). For all groups, the standard deviation (SD) was minimal, which indicates that the method as well as the system had a high reproducibility.

In the present study, the load level of the unloading plateau was represented by the load value detected at a deflection of 1500  $\mu\text{m}$ . Table 2 shows the load values and their mean at deflection of 1500  $\mu\text{m}$  during unloading and Figure 4 the mean values of all groups. The load values of the ligation groups were two to three times greater than those of the control: 1.49 N for the NBL, 3.90 N for the SSL, 3.02 N for the SL, and 4.37 N for the EL ( $P<0.01$ ).

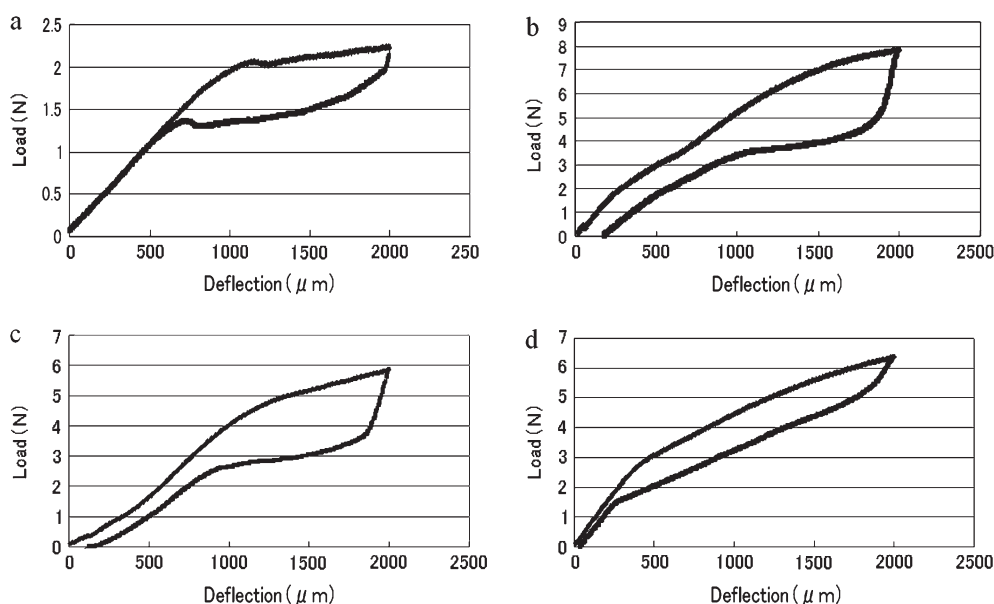
Repeated-measures ANOVA showed the significance of the interaction ( $P<0.05$ ) between deflection and ligation mode (Table 3). The graph of estimated marginal means (Figure 5) showed an apparent reversal of load order between SSL and EL during unloading from 2000 to 1500  $\mu\text{m}$ .

## Discussion

Setting of the bending speed was one of the main concerns because different speeds have been used previously. For example, Hamanaka *et al.* (1989) used 200  $\mu\text{m}/\text{seconds}$ , Watanabe (1982) 50  $\mu\text{m}/30$  seconds, and Garrec and Jordan, (2004) and Garrec *et al.*, (2005) 33  $\mu\text{m}/\text{seconds}$ . One of the reasons for this variation seems to have been the performance limits of the respective bending machines, but no specific reason was given. The speed in the present investigation was set at a relatively slow 10  $\mu\text{m}/\text{seconds}$  to allow comparison with the previous studies, although it was considered that an ideal speed would be even slower, as would occur clinically. This was only possible by making use of one of the advantages of the modified three-point bending system, which allows a wide choice of speeds.

Table 1 shows load values detected at a deflection of 2000  $\mu\text{m}$  and their means for all the four methods. The use of the Straight Shooter® in ligating with ELs and the monitoring of the force effect of the ligation procedure while ligating SSLs seem to have minimized intrapersonal variation in the ligation procedure. This can be inferred from the rather small SD values of the five measurements of load values for EL and SSL (Tables 1 and 2). These small SD values also reflect the reliability and reproducibility of the system.

For NBL, the mean load detected at a deflection of 2000  $\mu\text{m}$  was 2.24 N (Table 1), which is in agreement with the result reported by Watanabe *et al.* (1982), who set their bending speed to 50  $\mu\text{m}/30$  seconds. In the present study, the NBL method was adopted to form a control group of data that would, as far as possible, reflect the true properties of the NiTi wire with no influence of ligation.



**Figure 3** Load–deflection curve of nickel–titanium wire with (a) no bracket-and-ligation, (b) stainless steel ligature, (c) slot lid, and (d) elastomeric ligature.

**Table 1** Load values at a maximum deflection of 2000  $\mu\text{m}$  for the respective ligation methods.

	NBL	SSL	SL	EL
	2.33	8.06	5.96	6.44
	2.22	7.66	5.86	6.28
	2.24	7.82	5.94	6.33
	2.17	7.57	5.80	6.43
	2.24	8.05	5.68	6.41
Mean	2.24**	7.83**	5.85**	6.38**
SD	0.06	0.22	0.12	0.07

NBL, neither bracket nor ligation; SSL, stainless steel ligature; SL, slot lid; and EL, elastomeric ligature; SD, standard deviation.

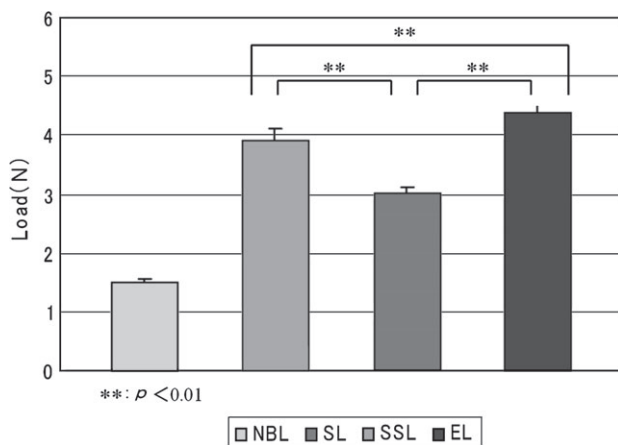
\*\* $P < 0.01$ .

**Table 2** Load values at a deflection of 1500  $\mu\text{m}$  during unloading for the respective ligation methods.

	NBL	SSL	SL	EL
	1.56	3.92	3.09	4.39
	1.41	4.18	3.15	4.42
	1.47	3.85	2.99	4.34
	1.52	3.60	2.99	4.50
	1.50	3.95	2.91	4.19
Mean	1.49**	3.90**	3.02**	4.37**
SD	0.05	0.21	0.10	0.11

NBL, neither bracket nor ligation; SSL, stainless steel ligature; SL, slot lid; EL, elastomeric ligature; SD, standard deviation.

\*\* $P < 0.01$ .

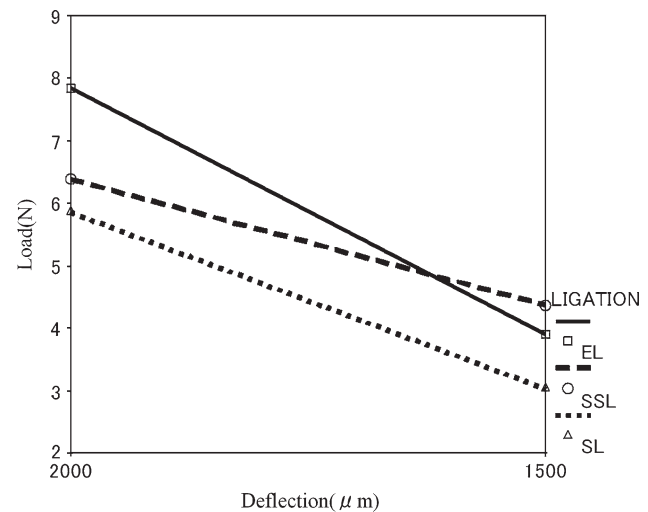
**Figure 4** Comparison of mean load values at deflection of 1500  $\mu\text{m}$  of all four methods including that with no bracket-and-ligation (NBL), stainless steel ligature (SSL), slot lid (SL), and elastomeric ligature (EL).

Among the ligation groups measured at deflection of 2000  $\mu\text{m}$ , the SSL group exhibited the greatest mean load, 7.83 N, and the SL the smallest, 5.85 N, with the referential NBL exhibiting 2.24 N (Table 1). The results suggest that the ligation system has the effect of increasing the load by a factor of two to three. It can also be inferred from this result that the increased amount of load corresponds to the force

**Table 3** Results of repeated—measures ANOVA of variables and their interaction.

Source	<i>F</i>	Significance
Ligation	1421.828	0.000
Deflection	4513.495	0.000
Deflection $\times$ ligation*	359.181	0.000

\*Interaction of deflection with ligation.

**Figure 5** Graph of estimated marginal means of load during unloading from 2000 to 1500  $\mu\text{m}$  for the stainless steel ligature (SSL), slot lid (SL), and elastomeric ligature (EL)

required in the ligation procedure to engage the wire in the slot. Clinically, the load difference due to the variation of ligation methods may affect the level of discomfort experienced by the patient, who may feel more discomfort with the SSL method and less with the SL.

If the load–deflection curves (Figure 3) are compared, an obvious difference in the unloading curves among the different ligation methods can be seen. The NBL group exhibited an apparent plateau demonstrating that the specimen wire possessed the expected superelastic property of typical NiTi wire (Figure 3a). For both the SSL and SL groups, there was also an apparent unloading plateau (Figure 3b,c). In the EL group, however, no unloading plateau was observed (Figure 3d); its load–deflection curve during unloading appeared almost linear and similar to stainless steel wires. This result can be interpreted as the disappearance of the superelasticity of the NiTi wire.

As can be seen by comparing the mean load values at a deflection of 1500  $\mu\text{m}$  (Table 2), the EL group showed the greatest load, 4.37 N, followed by the SSL 3.90 N, and the SL 3.02 N. Compared with the result obtained at a deflection of 2000  $\mu\text{m}$ , the order of load magnitude was reversed between the SSL and the EL. It was considered that both the disappearance of the unloading plateau in the EL and the

reversal of the load magnitude order between the SSL and the EL was due to the effect of the elastic properties of the EL. Its elasticity is expected to give a continuously tightening pressure to the specimen wire in the bracket slot, whereas this is not possible in the case of the SSL. This pressure, which can also be regarded as a frictional force, may be restraining the intrinsic mechanical behaviours of the NiTi wire. This is supported by the result of the repeated-measures ANOVA, which showed a significant interaction (Table 3). This assumption is also consistent with Ireland *et al.* (1991), who reported that ligation with EL exhibited significantly more friction than that with SSL. For the SSL, a tightening pressure will be exerted only in the early stage after ligation because of the high plasticity possessed by the fairly thin SSL. The SL group showed the smallest load value of 3.02 N (Table 2). This result is in accordance with Tecco *et al.* (2005), who reported that self-ligation brackets such as the Damon® bracket exhibited less friction than any conventional bracket. As shown in Figure 3c, the unloading plateau is formed at a level of 3.0 N. The result demonstrates that the SL is the ligation method that can facilitate the greatest possible exhibition of superelasticity by the NiTi wire.

## Conclusion

1. The ligation of brackets may result in the NiTi wire exhibiting significantly heavier loads and significantly different load–deflection curves from those traditionally expected.
2. The load traditionally expected to be generated by the true properties of the NiTi wire may be doubled or tripled by the act of ligation when measured in the unloading plateau region.
3. The EL may act as a restraint on NiTi wire by limiting superelasticity.
4. Of the three different ligation methods, the SL to allowed the superelastic properties of NiTi to be expressed.

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