

A comparison of space closure rates between preactivated nickel–titanium and titanium–molybdenum alloy T-loops: a randomized controlled clinical trial

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SUMMARY The purpose of this study was to conduct a prospective randomized controlled clinical trial to evaluate the rate of space closure and tooth angulation during maxillary canine retraction using preactivated T-loops made from titanium–molybdenum alloy (TMA) and nickel–titanium (NiTi).

Twelve patients (six males and six females) aged between 13 and 20 years who had upper premolar extractions were included, and each acted as their own control, with a NiTi T-loop allocated to one quadrant and TMA to the other using a split mouth block randomization design. The loops were activated 3 mm at each visit to deliver a load of approximately 150 g to the upper canine teeth. Maxillary dental casts, taken at the first and each subsequent monthly visit, were used to evaluate changes in extraction space and canine angulation. All used T-loops were compared with unused loops in order to assess distortion. Mixed model statistical analysis was used to adjust for confounding variables.

The mean rate of canine retraction using preactivated NiTi and TMA T-loops was 0.91 mm/month (± 0.46) and 0.87 mm/month (± 0.34), respectively. The canine tipping rates were 0.71 degrees/month (± 2.34) for NiTi and 1.15 degrees/month (± 2.86) for TMA. Both the rate of space closure and the tipping were not significantly different between the two wire types. The average percentage distortion of the TMA T-loop was 10 times greater than that of the NiTi loops when all other variables were matched.

There was no difference in the rate of space closure or tooth angulation between preactivated TMA or NiTi T-loops when used to retract upper canines. The NiTi loops possessed a greater ability to retain and return to their original shapes following cyclical activation.

Introduction

The T-loop design for orthodontic space closure has been comprehensively studied, particularly loops made from titanium–molybdenum alloy (TMA; Faulkner *et al.*, 1989; Hoenigl *et al.*, 1995; Kuhlberg and Burstone, 1997; Chen *et al.*, 2000; Thiesen *et al.*, 2005; Martins *et al.*, 2008a,b, 2009). The T-loop design generally provides: a constant moment:force (M:F) ratio, a light and constant force throughout the entire activation range of a closing loop, and a constant low load–deflection rate (Burstone, 1966, 1982; Burstone and Koenig, 1976). The load–deflection rate, also known as the force–deflection rate, defines force per unit activation or the rate of decay of force in a closing loop. The lower the load–deflection ratio, the greater the deflection or the greater the moment that can be applied without permanent deformation. Different authors have demonstrated that reduction of the cross-section of a wire, increased height of a spring or loop, and placement of helices strategically in a loop facilitates delivery of optimal force over a large range of deflection (Burstone *et al.*, 1961; Burstone and Koenig, 1976; Braun and Marcotte, 1995). A low load–deflection

rate can also be achieved using a wire material with a lower modulus of elasticity, such as TMA, instead of stainless steel. Little has been published on the use of superelastic nickel–titanium (NiTi) alloys for the construction of T-loops. These alloys have a characteristic plateau phase on their force–deflection curve, which coincides with transformation of the wire crystal structure from austenite to martensite, known as ‘stress-induced martensite’ or SIM (Miura *et al.*, 1986; Kusy, 1997).

NiTi T-loops have been shown to exhibit less force decay than TMA T-loops over clinically useful ranges, while the addition of preactivation bends to NiTi T-loops gives an optimum M:F of approximately 10:1, a useful aid to bodily movement (Kum *et al.*, 2004; Rose *et al.*, 2009). The clinical application of NiTi loops has been demonstrated in a case report, where a 5 mm extraction space was closed with a single activation (Bourauel *et al.*, 1997). Such applications have the potential to reduce the number of patient visits and increase practice efficiency.

Intervals between appointment visits are commonly shorter during the space closure phase due to the type of

force delivery system employed, which decay between visits to such an extent that reactivation or replacement is required. Practice efficiency could be enhanced by efficient force-delivering systems that allow longer intervals between visits, while maintaining clinically useful forces. The objectives of this study were to conduct a clinical randomized control trial to compare orthodontic T-loops made of NiTi with those made of TMA with respect to the rate of upper arch space closure during canine tooth retraction, the effect of the loops on canine tooth angulation, and the dimensional stability of the T-loop designs.

Subjects and methods

Ethical approval was obtained from the Lower South Regional Ethics Committee, New Zealand (project number LRS/07/08/034).

Twelve eligible subjects were recruited from the orthodontic clinic at the University of Otago Dental School, with an equal number of male and female participants. Their ages ranged from 13 years 3 months to 20 years 1 month, median 14 years 4 months. A sample size of 12 with a paired design was determined to obtain adequate power (80 per cent at $P = 0.05$) to detect an effect size of 0.85 mm, based on the rate of space closure for conventional TMA at 1.73 ± 1.36 mm/month (Kuhlberg and Priebe, 2003). The subjects were eligible for participation if they required full fixed appliance treatment, had upper premolar extractions (10 had the first premolars and 2 the second premolars extracted), had spaces distal to the canine teeth of 3 mm or more following levelling and alignment, and were compliant with treatment. Individuals were excluded from this study if they had any one of the following features: previous fixed orthodontic treatment, extractions other than the upper premolars or non-extraction, nickel sensitivity, poor oral hygiene, periodontal attachment loss exceeding 25 per cent of the root length (Kuhlberg and Priebe, 2003), significant pre- or in-treatment root resorption, or were non-compliant.

A split mouth cross-quadrant paired design (Glavind, 1977) was used, which allowed each participant to act as their own control. Randomization for NiTi loop allocation to specific upper quadrants was achieved using a block randomization method proposed by Roberts and Torgerson (1998), and the TMA loop was used on the contralateral side.

The T-loops used in this study were made from 0.018 × 0.025 inch superelastic Japanese NiTi (Neo Sentalloy, F-100; GAC, Bohemia, New York, USA). The laboratory protocol for the T-loop fabrication has been described previously (Kum *et al.*, 2004; Rose *et al.*, 2009). Briefly, straight lengths of NiTi wire were formed around a steel template to produce the desired shape, including preactivation bends of 30 degrees on each leg. The template and wire were then heated to and held at 510°C for 9

minutes in a crown furnace (Programat® P500; Ivoclar Vivadent AG, Schaan, Liechtenstein), before being allowed to bench cool.

The TMA loops were adapted from 0.017 × 0.025 inch 'reverse curve' TMA wires with T loops (Ormco, Orange, California, USA). The alpha- and beta-legs of both the TMA loops were preactivated to 30 degrees from the horizontal.

The teeth were bonded using the Wick Alexander prescription, 0.018 inch slot Mini-Taurus design (Rocky Mountain Orthodontics, Denver, Colorado, USA) preadjusted edgewise system with a vertical slot. The upper first permanent molars were either banded (3M Unitek Victory Series, Monrovia, California, USA) or bonded (0.018 inch Double weldable Accent® Buccal Tubes; Ormco) to provide an auxiliary tube gingival to the archwire tube.

Initial levelling and alignment commenced with a 0.014 inch round NiTi wire in all cases and progressed to 0.016 × 0.022 inch rectangular stainless steel wire, which was left *in situ* for at least 4 weeks to ensure full expression. During canine retraction, the upper rectangular steel wire was utilized as a base archwire while the canines were retracted by the T-loops, which were used as auxiliary springs. The upper canine was ligated with a 0.010 inch steel ligature to reduce the effect of rotation. The steel base arch was assessed at each visit for distortion. T-loops were fitted into the auxiliary molar tubes and connected to the upper canine bracket by means of a steel tube soldered to a T-pin (Rocky Mountain Orthodontics), which was seated in the vertical slot of the canine bracket. The closing loops were placed midway between the canine and molar teeth and activated by 3 mm, as measured by a dial calliper (Mitutoyo, Kawasaki, Japan). *In vitro* tests indicated that the force levels at 3 mm deactivation provided approximately 150 g deactivation load for both NiTi and TMA T-loops. The participants were reviewed at monthly intervals to ensure the amount of activation of each loop remained at 3 mm, and the residual activation and reactivation of NiTi and TMA loops were recorded at each visit. For subjects who had a high anchorage requirement, additional intra-oral anchoring strategies were designed such that no additional forces were placed directly on the canine teeth. Class II elastics (10 participants) were worn to hooks on the upper archwire, which also had stops mesial to the molar teeth to re-enforce molar anchorage. A Nance appliance was used in two patients and temporary anchorage devices (Vector TAS, 8 mm; Ormco) were used in one to support molar position. In these instances, supplemental anchorage was provided to the maxillary posterior teeth independent of the canine in order to resist molar mesial movement during reciprocal space closure. Only one patient did not have anchorage support.

Upper dental impressions were taken at the start and at each visit to assess space closure. The study was discontinued

for each participant before the canine retraction was fully completed on either side of the arch or once the canine teeth reached a Class I relationship. This ensured that the T-loops remained active for the duration of the study (Bokas and Woods, 2006). The rate of space closure was evaluated based on the amount of space closure achieved per month as measured on the upper dental casts.

The patients were unaware which closing loop was used on either side of the mouth. Measurements on the dental casts were performed by a single operator (FYK), who was also blind as to which loop was used on either side (it was not possible to determine which side the NiTi was used from the casts). However, as the two loops differed slightly in the cross-sectional dimension, it was not possible to blind the clinical operator to the type of the loops used at the clinical appointments. Each recording was repeated by the same operator after a period of at least 1 week.

The most distal surface of the upper canine and the most mesial surface of the upper premolar were chosen as reference landmarks to record the linear distance across the extraction space on the dental casts, which was measured to the nearest 0.01 mm using a digital calliper (Model 500-196-20, Mitutoyo). The dental casts were also scanned into digital images using a three-dimensional model scanner (3Shape A/S, Copenhagen, Denmark) and viewed by Zeno Manager Software (Wieland i-mes Dental Solutions, Eiterfeld, Germany). Once the digital image of a particular quadrant was obtained, a transverse plane was created using the same reference landmarks as on the model, and this was orientated so that the plane was sectioned across the extraction space. The instrument was calibrated daily, in accordance with the manufacturer's recommendations. A second measurement was repeated at least 1 week after the first and an average value was obtained. The rate of space closure was expressed in millimetres of change per month.

Used T-loops were collected from all 12 subjects and a digital image was taken (Fuji finePix S2 pro, Tokyo, Japan). The used loops were compared with new TMA and NiTi loops, respectively. The internal area of each T-loop was measured by tracing along the internal 'T' configuration. A reference scale was set to 186.88 pixels/cm using the scale on the image and kept constant for each area measurement using ImageJ software (<http://rsbweb.nih.gov/ij/>). All area measurements were recorded in square centimetres. Each loop area was measured twice at least 1 week apart and the average was taken. The amount of distortion was represented as a percentage of the area value of each used T-loop compared with those of the unused T-loops.

Upper canine angulation was measured by projecting the long axis of the canine and measuring the angle against a constructed occlusal plane. A stent for the upper canine teeth was made from the dental cast obtained at the placement visit using clear polyvinylsiloxane bite registration material (Peppermint Snap; Discus Dental, Culver City, California, USA) to cover the cuspal portion of

each upper canine. A length of rectangular stainless steel wire (0.016 × 0.022 inch) was embedded in the stent, parallel to the long axis of the crown, as viewed from the buccal side. The occlusal plane was approximated by placing a 2 mm clear acrylic plate on the upper cast, resting usually on the incisal edges and the palatal cusps of the first molars (modified from Ziegler and Ingervall, 1989). A digital image of each cast was taken with the reference post and the occlusal plane in place, with the occlusal plane perpendicular to the digital camera to minimize parallax. The canine angle relative to the occlusal plane was measured using ImageJ software. The same reference post and occlusal plane were used to measure the angulation of the canine at the end of the study.

Statistical analyses were performed using Stata (version 10; Stata, College Station, Texas, USA) using mixed model analyses adjusted for potentially confounding variables such as unequal amounts of extraction space present at the start of the trial, potential differences between the upper left and upper right sides of the same mouth, duration of treatment, and the type of the T-loops placed. The degree of measurement error was calculated using the formula of Dahlberg (1940):

$$S = (\sum d^2) / 2n,$$

Where S is the standard error, d is the difference between the first and the second set of the measurements, and n is the number of measurement in each set. Statistical significance was defined as P -values <0.05.

Results

The intra-examiner error analysis for each of the variables investigated was 0.07 mm for the linear space closure measurement, 0.5 degrees for the angular measurement, and 1.9 per cent for area distortion. There were no statistically significant differences between the linear measurements obtained from the dental cast by digital calliper and those using the three-dimensional model scanner ($P = 0.916$).

All 12 patients were followed throughout the trial period. The overall treatment duration during space closure to achieve a Class I canine relationship ranged between 2 and 6 months. The average treatment duration was 3 months 2 weeks. Three participants had been in the trial approximately 4 months when the T-loop pairs needed to be removed prematurely to allow timely completion of the clinical trial. All three finished with a quarter unit Class II canine relationship with approximately 2 mm of space distal to the canines. The remaining nine participants had a Class I canine relationship at the time of T-loop removal. The means for the rate of space closure for the NiTi and TMA loops were 0.91 mm/month (± 0.46) and 0.87 mm/month (± 0.34), respectively (Table 1). The mean difference between the rates of space closure produced by the two

Table 1 Monthly rate of space closure obtained using either nickel–titanium (NiTi) or titanium–molybdenum alloy (TMA) T-closing loops activated to 3 mm (approximately 150 g deactivation force) at each visit.

	Number	Maximum	Minimum	Mean	SD
NiTi T-loop (mm/month)	12	1.90	0.31	0.91	0.46
TMA T-loop (mm/month)	12	1.32	0.12	0.87	0.34
Rate difference (mm/month)				0.022	0.39
Rate difference after adjustment				0.07*	

* $P = 0.848$ (95 per cent confidence interval: -0.70 to 0.86).

Table 2 Changes in upper canine angulation with either nickel–titanium (NiTi) or titanium–molybdenum alloy (TMA) T-closing loops from start to final position.

Change in angulation	Number	Range	Mean (\pm SD)
NiTi T-loop ($^{\circ}$)	12	-8.79 to 9.33	$2.15(\pm 5.13)$
TMA T-loop ($^{\circ}$)	12	-2.3 to 16.27	$4.46(\pm 6.38)$
Angle difference after adjustments			1.20 (95% confidence interval: -2.54 to 4.94)

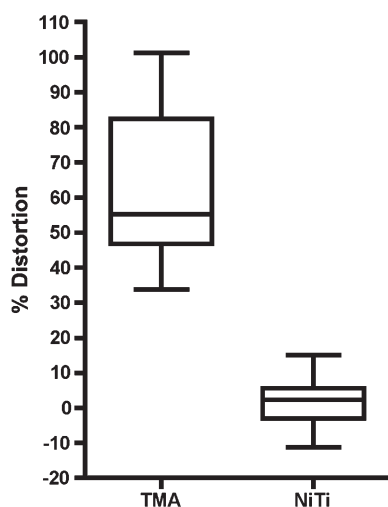


Figure 1 Box and whisker plots illustrating the distortion in the nickel–titanium (NiTi) and titanium–molybdenum alloy (TMA) T-loops

T-loops after adjustment was 0.07 mm/month (95 per cent confidence interval: -0.70 to 0.86 ; $P = 0.848$).

The mean changes in canine angulation are illustrated in Table 2. The changes in angulation were obtained by subtracting the angles at the start from those at the end of the study. The ‘minus’ sign denotes mesial tipping of the canine crown. Three of 12 canines in the NiTi group had forward crown movement whereas in the TMA group, four of 12 canines had forward crown movement.

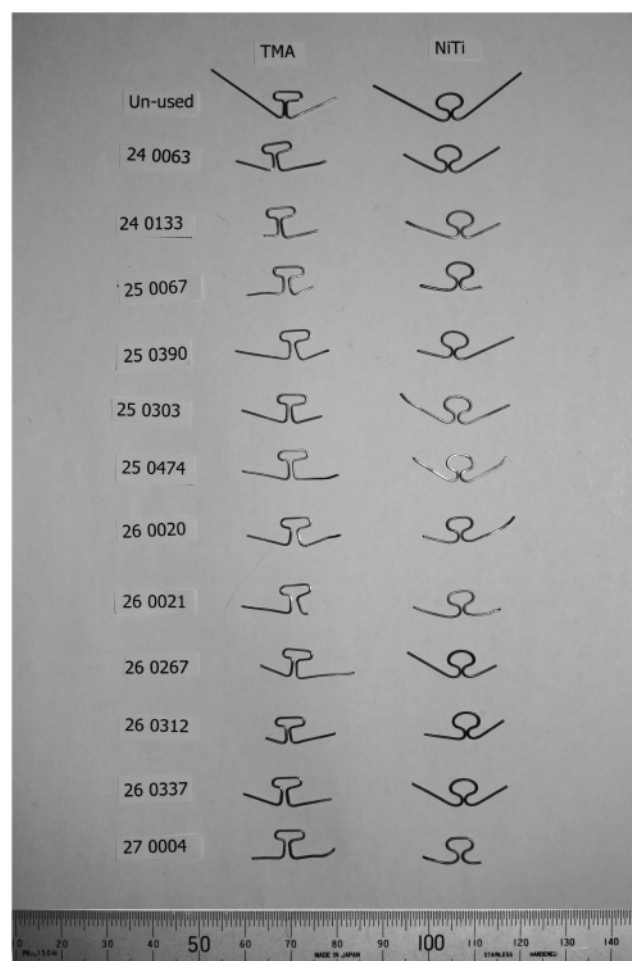


Figure 2 An overview of all the nickel–titanium (NiTi) and titanium–molybdenum alloy (TMA) preadjusted T-closing loops used in this clinical trial. TMA T-loops appeared to undergo gross loop distortion. In comparison, the NiTi loops maintained their initial configuration. Person ID 26 0020 had the shortest trial duration of 2 months and ID 27 0004 had the longest trial duration of 6 months.

Figure 1 shows the percentage distortion in each of the T-loop designs. The distortions for TMA T-loops ranged from 33.8 to 101.3 per cent compared with the unused loop, whereas the range for NiTi T-loops was from less than 0 to 15 per cent. The average percentage distortion of the TMA T-loop was 10 times greater than that of the NiTi T-loop. Figure 2 shows the 12 specimens after use compared with unused loops.

Discussion

The rate of space closure for both loops approximated 1 mm/month. This is in agreement with suggested rates of tooth movement (Proffit, 2000). A similar finding for the rate of canine retraction was observed by Thiruvengkatachari *et al.* (2008), where the rate of canine retraction ranged between 0.81 and 0.93 mm. The decision to use a passive

stainless steel base archwire was intended to control the rotational and vertical effects of the sectional T-closing loop during canine retraction. This was supported by two other studies (Articolo and Kusy, 1999; Hamdan and Rock, 2008). The T-closing loops in this study had preactivation bends, which in theory would enhance the tendency towards bodily movement and thus reduce the tendency for the bracket to bind on the base archwire. Nonetheless, the canines were retracted using sliding mechanics and, therefore, there was an anticipated resistance to sliding. Eleven of the 12 patients had upper molar anchorage re-enforcement, mainly by the use of Class II elastics to hooks on the upper archwire, in combination with stops mesial to the upper first molars. This would mean that space closure was not truly reciprocal and tended to occur by distal movement of the canine, although anchorage supplementation would depend on compliance with Class II elastic wear. For the patient who had no additional anchorage, space closure for both sides approximated 0.7 mm/month, which was slightly less than the mean space closure, suggesting that lack of additional anchorage did not result in faster space closure.

A varied biological response was observed for all 12 participants. In the NiTi group, the 'slowest' rate of movement was 0.31 mm/month and the 'fastest' 1.90 mm/month. Similar variation was observed for the TMA group, where the slowest rate was 0.12 mm/month and the fastest 1.32 mm/month. Intra-personal difference was also noted. For example, in one subject, the right (TMA) side of the mouth achieved only 0.38 mm cumulative change whereas the left (NiTi) side achieved 1.95 mm over a 3 month period. Left and right side variation could not be explained by the occurrence of premature deformation of the TMA T-loops as in another individual the side with the deformed TMA resulted in more extraction space closure than that found on the NiTi side, although the canine was tipped more by the TMA loop.

Intra-individual variation also existed for canine angulation, which could have arisen as a result of constant change in the centre of rotation during retraction due to different moments generated by each loop design. It is also feasible that the use of Class II elastics to the base arch may have caused a cant of the occlusal plane, thus adversely affecting canine inclination, although this would be expected to be similar on both sides. The base archwire in this study was used to control and minimize tipping (and rotation) of the canines during retraction, although this was at the expense of frictional resistance and binding. The base arch also limited the ability to examine the true movement that would have occurred had a loop been used on its own.

Sample size in orthodontic clinical studies is a perennial problem and this study suffered from a similar shortcoming. However, the number of participants matched the number required as determined by the power calculation and was also identical in number to similar previous investigations (Bokas and Woods, 2006).

It was interesting to note that TMA T-loops had become permanently deformed within the 3 mm activation range, which implies that actual force delivery was less than would be expected, and could possibly lead to a cessation in canine retraction once the loop had reached its new resting position. This would result in an 'intermittent' force to the tooth and necessitate more frequent visits for reactivation. NiTi T-loops, on the other hand, consistently showed their ability to return to the predetermined shape following *in vivo* use. NiTi loops were less able to deliver a continuous deactivation force that approximated 100 g when deactivated from 3 to 1 mm or less. Previous studies have shown that it is possible to activate NiTi up to 8 mm opening and still deliver a continuous low force range during canine retraction (Rose *et al.*, 2009), which will allow increased intervals between visits, thus enhancing overall practice efficiency.

Conclusions

1. There is no statistically significant difference in the mean rate of space closure between preadjusted NiTi T-loops and preadjusted TMA T-loops when used in combination with a base arch.
2. There is no statistically significant difference in the mean change in canine angulation per month following space closure between preadjusted NiTi T-loops and preadjusted TMA T-loops.
3. The preadjusted NiTi T-loops maintained their preactivation configuration and underwent less change in shape than the TMA T-loops following space closure. The TMA T-loops underwent 10 times more distortion than the NiTi T-loops.

The current study shows the promising properties of the NiTi T-loop with its high springback and ability to deliver a continuous constant low force during deactivation. Furthermore, randomized clinical trials are warranted to confirm the potential use of NiTi T-loops in clinical orthodontic practice.

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