

The Analysis of Load/Deflection of Four Simple Closing Loop Designs by Using Universal Testing Machine

การวิเคราะห์อัตราของแรงต่อระยะทางคืนกลับของลวดสปริงดัดฟันแบบง่ายสี่รูปแบบโดยใช้เครื่องทดสอบแรงทั่วไป

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ABSTRACT

This investigation studied load/deflection (LDR) of four simple orthodontic closing loops: U loop, helical loop, U loop with reversed arms and helical loop with reversed arms by Universal Testing Machine (UTM). The 30 loops per each design were hand formed of 0.019x0.025 inch SS wire and tested on the UTM-LR 30 K-Lloyd instrument. The results revealed that the load/deflection rate (LDR), from the lowest to the highest, for the helical loop with reversed arms, the helical loop, the U loops and then the U loop with reversed arms were 2.72 ± 0.56 , 3.11 ± 0.45 , 4.00 ± 0.43 and 5.07 ± 0.75 N/mm, in that order. From ANOVA and Post Hoc Tests, the means of LDR of the four studied loops were significantly different when compared to each other ($p < 0.001$). The maximum deflection limit was reported by UTM suggested that the extension distance of the four closing loop designs do not exceed 2 mm.

บทคัดย่อ

งานวิจัยนี้ศึกษาอัตราของแรงต่อระยะทางคืนกลับของลวดสปริงดัดฟันแบบง่ายสี่ชนิดได้แก่ ลวดสปริงรูปตัวยู ลวดสปริงข้อเกลียว ลวดสปริงรูปตัวยูที่มีขาไขว้ และ ลวดสปริงข้อเกลียวที่มีขาไขว้โดยเครื่องทดสอบแรงทั่วไป ลวดสปริง 30 เส้นต่อชนิดถูกดัดขึ้นรูปด้วยมือโดยใช้โลหะเหล็กกล้าไร้สนิมขนาด 0.019 x 0.025 ตารางนิ้ว และทดสอบโดยใช้เครื่องทดสอบแรงทั่วไปรุ่นแอลอาร์สามสิบเคลอยด์พบว่าอัตราของแรงต่อระยะทางคืนกลับเรียงลำดับจากน้อยไปหามากดังนี้ ลวดสปริงข้อเกลียวที่มีขาไขว้ ลวดสปริงข้อเกลียว ลวดสปริงรูปตัวยู และ ลวดสปริงรูปตัวยูที่มีขาไขว้มีค่า 4.00 ± 0.43 2.72 ± 0.56 3.11 ± 0.45 และ 5.07 ± 0.75 นิวตันต่อมิลลิเมตรตามลำดับ จากการทดสอบค่าสถิติด้วย One-way ANOVA และ Tamhane post hoc test

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ค่าเฉลี่ยของลวดทั้งสี่ชนิดแตกต่างกันอย่างมีนัยสำคัญ ($p < 0.001$) นอกจากนี้ ขอบเขตระยะทางคืนกลับสูงสุดที่รายงานโดยเครื่องทดสอบแรงทั่วไปบ่งบอกว่าระยะทางในการยืดลวดสปริงดึงฟันแบบง่ายสี่ชนิดไม่ควรเกิน 2 มิลลิเมตร

Key Words : Load/deflection, Orthodontic closing loop, Universal testing machine

คำสำคัญ : อัตราของแรงต่อระยะทางคืนกลับ ลวดสปริงดึงฟันแบบง่าย เครื่องทดสอบแรงทั่วไป

Introduction

Space closure is one of the common steps in the orthodontic treatment. The causes of spacing problems come from permanent tooth extraction, tooth-arch size discrepancy (small teeth, large jaw), trauma, missing tooth follicle, and extraction to gain the spaces to align crowded dental arches. To solve the spacing problem, several types of mechanics are available. Popular orthodontic mechanics include inter- and intra- maxillary elastic bands, power chain elastics, tension coil springs, and loop arch mechanics. An orthodontic loop is a spring of various possible configurations used to lower the load/deflection (LDR) by addition of more wire to achieve frictionless tooth movement, to avoid the inconsistency of the force system delivered by a plain wire, and to achieve dissociation of forces and moments (Daskalogainnakis 2000). Moreover, their physical properties help for absorbing energy without excessive peak loads to a tooth, applying a definite force to the teeth, supporting the moving masses of teeth, and force control (Wahl 1949). The closing loops can be divided into 3 groups; the first group is the simple closing loops. The second group comprises loops with reversed arms. The last group is modified closing loops.

Load/deflection (LDR) is the external loading needed for unit deformation (Yang et al, 2001). In orthodontics, LDR is signified by the

unit length deformation by a generated force. Orthodontic arch wires and springs with high LDR not only apply excessive force on teeth, but their strength decreases quickly with tooth movement. It is expressed in terms of force per unit displacement of the spring, and LDR is measured in N/mm (g/mm). A spring with a low LDR is capable of generating forces that are approximately constant over the working range of the spring and do not depend so much on the amount of activation (Daskalogainnakis 2000). The LDR can be increased or reduced by wire cross-section, wire length, wire material properties, wire configuration (shape and design) and constraint conditions (ligation between two teeth, a wire segment tightly ligated delivers a much higher LDR than a ligated in only one of the brackets) (Yang et al, 2001). Schillai and Lehmann (1989) found that the LDR of orthodontic closing loops is proportional to the modulus of elasticity of the utilized alloys and the spring geometry, the more wire length used for shaping the loops, the lower the LDR. Odegaard et al (1996) concluded from their study that 1) Increasing the length of a closing loop leads to the greatest increase in flexibility compared with other loop designs. 2) Increasing the diameter of the loop's arch or helix part of a closing loop will increase the loop flexibility. From all the above, it can be said that an essential property of all these loops is

their LDR. There have been numerous publications about these closing loop springs. But it is surprising that there have been few papers reporting LDR of the plain loop type and comparing this property with that of reversed arms loops. The purpose of this study was to experimentally compare the LDR of four loop designs (Figure 1), which are the U loop, helical loop, U loop with reversed arms, and helical loop with reversed arms, using finite element analysis (FEA) and experimental testing by a Universal testing machine (UTM).

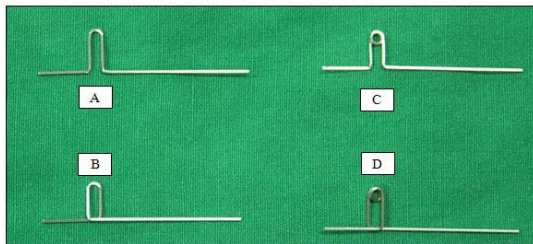


Figure 1 Four closing loops in this study, A. U loop, B. U loop with reversed arms, C. helical loop and D. helical loop with reversed arms

Methods

This study was a laboratory trial carried out by UTM. All closing loop were bent from 0.019x0.025 inch rectangular stainless steel wire (ORMCO) with the round beak (2 mm diameter) Young loop pliers for loop apex bending. All loops were produced as a canine retraction loop of sectional arch using the size of one side matching the dimension of one side of a dental arch consisting of an upper canine, first and second premolar and first molar (Woelfel & Scheid, 2001). The size and shape of the closing loops were added the wire length at end terminal for UTM arm holders (Figure 2).

From figure 2, total size were 38 mm; the length of anterior portion was 6 mm and 22 mm of posterior portion. Besides, added 5 mm per terminal end for UTM holding arms. Before testing the LDR, a closing loop was tested for the maximum deflection. UTM extended the loop with rate of 1 mm per minute until the maximum yielding point. From this test, 2.5 mm was as the maximum distance. The sample size was calculated by a pilot study which used 5 loops per design for the LDR and the resulting data used to calculate the sample sizes. 30 loops per each type gave the Power of the test between 93 to 96%.

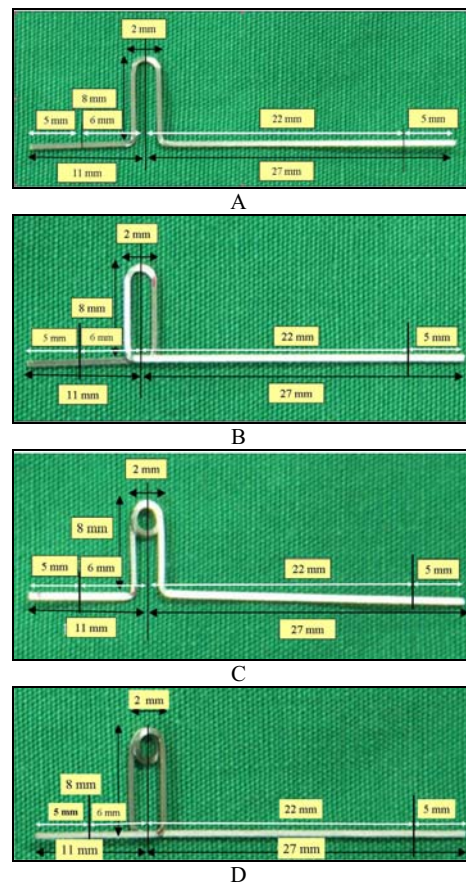


Figure 2 The characteristics of all hand-form closing loop. A. U loop, B. U loop with reversed arms, C. helical loop and D. helical loop with reversed arms.

The LDR was measured by The UTM which recorded the load values from small increments of deflection between 0 mm and 2.5 mm. The both end side of each loops were fixed 5 mm. As results, the rest length of the anterior was 6 mm and posterior portion was 22 mm. The total length between two arms was 28 mm (Figure 3).

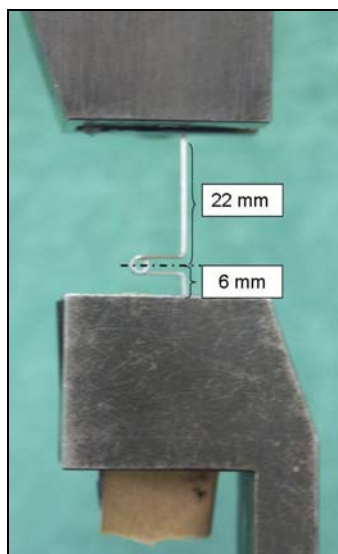


Figure 3 A helical loop spring retained in the UTM.

The test data from the UTM was transferred to Microsoft Excel program, then graphing the LDR for each spring.

Data Analysis

Statistical analysis for the UTM results used One-way ANOVA and Post Hoc Test (Tamhane) to compare the means of the LDR among the four closing loop designs.

Results

The average LDR of 30 loops per design from UTM are recorded in Table 1 and Figure 4.

Table 1 Averages and S.D of LDR of four simple closing loop designs

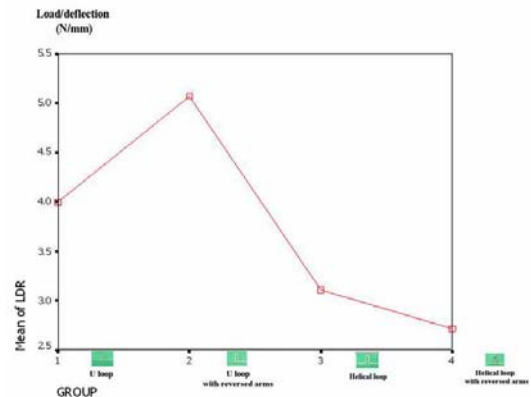


Figure 4 Linear diagram of LDR from UTM; the highest was U loop with reversed arms (2), the U loop (1) and the helical loop (3). The helical loop with reversed arms (4) was the lowest LDR.

The results show that the highest mean LDR was U loop with reversed arms, and then U loop, helical loop and helical loop with reversed arms correspondingly.

Comparative analysis for testing the relation between-groups and within-groups of load/deflection of the four closing loop of the LDR from UTM data was done by One-way ANOVA.

Table 2 One-way ANOVA presented the relation of the four closing loop designs

Dependent Variable Load/deflection	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	98.198	3	32.733	104.066	0.000
Within Groups	36.486	116	0.315		
Total	134.684	119			

In Table 2, there were differences of LDR between closing loop designs groups ($P < 0.05$).

The data was not homogeneous, so the

Tamhene Post Hoc Test for multiple comparisons was used to compare the different loop groups (Table 3)

From Table 3, it is concluded that all of the four closing loop designs were significantly different from each other. From the lowest to the highest of LDR, for the helical loop with reversed arms, the helical loop, the U loops and then the U loop with reversed arms, were 2.72 ± 0.56 , 3.11 ± 0.45 , ± 0.43 and 5.07 ± 0.75 N/mm, in that order.

Table 3 Post Hoc Tests used to check the groups difference

Type of Post Hoc Test	Load/deflection		Mean Difference (1-2)	Std. Error	Sig.	95% Confidence Interval	
	Main group(1)	Compare group(2)				Lower Bound	Upper Bound
Tamhane	U loop	U loop with reversed arms	-1.0690(*)	.1572	.000	-1.5012	-.6367
		Helical loop	0.8923(*)	.1127	.000	0.5853	1.1993
		Helical loop with reversed arms	1.2801(*)	.1290	.000	0.9277	1.6325
	U loop with reversed arms	Helical loop	1.9613(*)	.1590	.000	1.5247	2.3979
		Helical loop with reversed arms	2.3491(*)	.1710	.000	1.8821	2.8161
	Helical loop	Helical loop with reversed arms	0.3878(*)	.1312	.027	0.0298	0.7458

Besides, the deflection at maximum load per each loop also be recorded. The deflection at maximum load is the maximum displacement at the maximum load of the loops before reach to the yield point (0.1% permanent deformation).

Table 4 Comparison of the means and S.D of the deflection at maximum load on each design

No	The extension distance at maximum load average and standard deviation of Four closing loop design UTM (mm)			
	U loop	U loop with reversed arms	Helical loop	Helical loop with reversed arms
Average (means)	2.2833 (mm)	2.3561 (mm)	2.3056 (mm)	2.3426 (mm)
Standard deviation	0.1342 (mm)	0.1020 (mm)	0.1775 (mm)	0.1461 (mm)

From Table 4 shows that order of displacement at maximum load of four closing loops from the highest to the lowest was U loop with reversed arms, helical loop with reversed arms, helical loop and U loop.

Discussion

The load/deflection

From the results on Table 1, it reveal that the changing the simple closing loops to be various configurations and designs can significantly improved the property of the closing loops, especially the helical loop with reversed arms which be reduced the LDR to be the lowest, though all the studied loops were formed with the same material and instruments, height, width and helical diameter (Yang et al, 2000) (Siatkowski 1996) (Siatkowski 1997) (Burstone and Koenig, 1976) (Gjessing 1985) (Ungbhakorn et al, 2005)

It has been accepted that the increased wire length does decrease LDR. So, it was expected that the highest to the lowest LDR would be the U loop, the U loop with reversed arms, the helical loop and then the helical loop with reversed arms, But it was found using the UTM that the order from highest to the lowest load/deflection was U loop with reversed arms, the U loop, the helical

loop and then the helical loop with reversed arms. This disagreement finding of the UTM is difficult to explain. It may be possible that in certain length of wire, direction of force has different influence in LDR. For U loop and U loop with reversed arms, the length of wire was increased by overlapping of crossing arms on the loop. Additionally, direction of force when loading on the arc part of the loop has significant influence increasing the load/deflection of the spring composed of the U loop with reversed arms which is more influence than the influence of the wire length. Thus the U loop with reversed arms is higher load/deflection than U loop. It presented on Figure 5 A and B which showed that the arc was extended on U loop but squeezed on U loop with reversed arms.

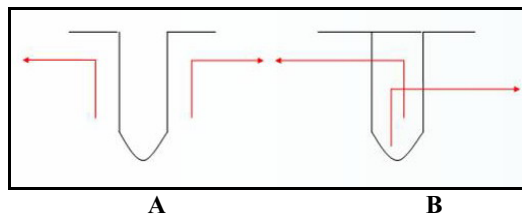


Figure 5 The direction of force which effected on the A. U loop and B. U loop with reversed arms

For helical loop and helical with reversed arms, wire length increased by overlapping of the reversed arms and helices, the helical loop with reversed arms is longer than helical loop. And direction of force has less influence than the influence of the wire length, load/deflection of the helical loop with reversed arms is smaller than the helical loop (Figure 6).

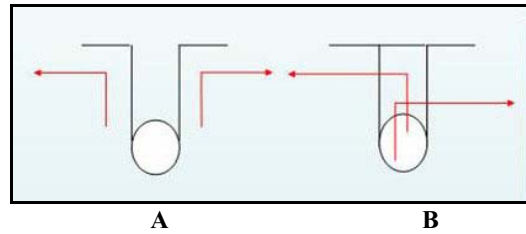


Figure 6 The direction of the forces affected on the helix of the loop, the length of the wire is more effect the LDR than direction of force A. helical loop, B. helical with reversed arms

From Figure 6 which compares the LDR with non-helix group, it also imply to confirm that an apical helix is a useful design to be mainly effective reducing the LDR and help to reduce a concentration of efforts and to produce a greater spring effect (Burstone & Koenig, 1976). When the spring is activated, the both legs of the loop come closer, becoming almost parallel at the maximum activation. In this way, a greater range of activation can be found because the spring is activated in the same direction as the original bending (Ferreira et al, 2005).

The different of the deflection at maximum load

The maximum load of four closing loops from the highest to the lowest was U loop with reversed arms, helical loop with reversed arms, helical loop and U loop. From data, it implies that the reversed arms group could be more extend than non-reversed arms group. However for the clinical application, they are not significantly different. One more thing, it also aware the clinicians, who use this four closing loop designs, do not activate the loops beyond 2 mm.

Clinical implications

Generally, The good available simple closing loops should be designed as following criteria: (1) clinicians can identify the magnitude of the total force system (2) LDR is low so that the force can be relatively light and constant and (3) the appliance should be easily modifiable at a clinician's need (Choy *et al*, 2002). Waters, 1981, stated that the closing loop could offer enough stiffness for the stabilizing sections of the arch and also offer flexibility where it is required. Gjessing (1985) and Braun *et al* (1997) recommended the optimal LDR for canine retraction is 50–200 gm which produces a maximum of desirable biologic response with minimum tissue damage, rapid tooth movement with little or no clinical discomfort forecastable dental movement and reducing the number of office visits. Besides, Roberts, Chacker and Burstone (1982) advised that the spring attraction force must be kept below 300 g to minimize anterior retraction and produce posterior protraction. Braun and Marcotte (1995) reported forces that optimal force varied from 50 to 300 g. From this study, the helical loop with reversed arms had loading of approximately 270 ± 57 gm is obtained when the two sections of the double helix are 1 mm.

From the study, these four closing loop design should not be separated more than 2.00 mm. Because it may be occurred plastic deformations on the closing loop if the activation was exceed. The simple closing loop designs which has a low LDR can produced is reasonably stable force, and reactivation is often not necessary. Moreover, the force system should easily be visualized, and modification of the system is relatively easy

for both initial and subsequent activation (Choy *et al*, 2002). The study showed that the knowledge of modified closing loop can reduce or increase the LDR by diverging the spring design, wire diameter, alteration of external loop size and number of external loop coils.

However, the condition of the loop activated ,loading or unloading, also affected. El-Sheikh, Godfrey, Manosudprasit and Viwattanatipa (2007) reported the loading and unloading curves which generally were linear, with a small area of hysteresis. The loading mean stiffness was significantly greater than the unloading mean stiffness, although this is clinically insignificant.

Limitation of the study

All the closing loops to be tested had to be hand-formed because of difficulties in designing a forming system to produce absolutely standardized loops. This may introduce some variations in the dimensions and work-hardened properties of the respective loops and, hence in the load/deflection properties.

Conclusion and Implication

The LDR for one closing loop should be as lowest as possible so that the force applied to the tooth will be low to minimize pathological effects on the periodontal support and also maintain close to constant force over a large deflection range. According to the tests, the helical loop with reversed arms provided the lowest LDR among the studied four simple closing loops designs. Wire bending to change the shape and configurations of the loops is the one procedure to improve or

change the force/deflection properties of the orthodontics wire material. The most effect to the LDR come from amount of the wire incorporated into a closing loop, more length of wire used resulting in lower LDR. From by-product of the study, it devised the clinicians and orthodontist about the extension distance for the four type of simple closing loop designs; U loop, U loop with reversed arms, helical loop and helical loop with reversed arms. The appropriate distance was not exceeding 2 mm. However, this suggests that even though UTM tested the LDR, it should be confirmed by other methods, such as clinical or other mathematical analysis, i.e. the finite element analysis.

Acknowledgements

We would like to thank all key informants and contact individuals who provided great assistance on the laboratory testing. In particular, this study gained supports for the research budgets from the Graduate Research Fund, Khon Kaen University.

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