Original article

A novel and simple design of the closing loop producing optimal force magnitude and moment-to-force ratio for en-masse retraction of anterior teeth

Satoshi Yamaoka,^a Ryo Hamanaka,^b Tuan anh Nguyen,^a Sachio Jinnai,^a Jun-ya

Tominaga,^b Yoshiyuki Koga,^c Noriaki Yoshida^d

^a PhD Graduate Student, Department of Orthodontics and Dentofacial Orthopedics, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan

^b Assistant Professor, Department of Orthodontics and Dentofacial Orthopedics, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan

^c Associate Professor, Department of Orthodontics, Nagasaki University Hospital, Nagasaki, Japan

^d Professor and Chair, Department of Orthodontics and Dentofacial Orthopedics, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan

Corresponding author: Noriaki Yoshida, Department of Orthodontics and Dentofacial Orthopedics, Nagasaki University Graduate School of Biomedical Sciences, 1-7-1 Sakamoto, Nagasaki 852-8588, Japan

E-mail: nori@nagasaki-u.ac.jp

Tel/Fax: +81-95-819-7667/7670

ABSTRACT

Purpose: The aim of this study was to clarify the mechanical conditions of loop activation that produce the optimal force system allowing controlled movement of the anterior teeth.

Materials and Methods: The closing loop examined in this study was a 10-mm-high teardrop type bent from a 0.017×0.025 -inch stainless steel archwire. A loop design that can generate a high moment-to-force (M/F) ratio and the optimal force magnitude was investigated by varying the rate of the cross-sectional reduction of the loop apex, the amount of loop activation and the degree of gable bend. Forces and moments acting on closing loops were calculated using structural analysis based on the tangent stiffness method.

Results: A force magnitude of 302 g and an M/F ratio higher than 10 (sufficiently high to achieve bodily movement of the anterior teeth) could be produced when the thickness of the cross-section of a 10-mm-high teardrop loop was reduced by half for a distance of 3 mm from the apex and a gable bend of 30° was incorporated into the loop.

Conclusions: The optimal force magnitude and M/F ratio for achieving controlled tipping or bodily movement of the anterior teeth can be produced by partially reducing the thickness of the teardrop loop, and by placing a gable bend of 20° to 30° in the 0.018-inch bracket slot system.

KEY WORDS: Loop mechanics; En-masse retraction; Tangent stiffness method; Gable bend; M/F ratio; Optimal force; Force system

INTRODUCTION

Loop mechanics had been widely used for space closure in the treatment of cases with four premolar extractions ever since the Tweed technique was established.¹ Sliding mechanics have now become more and more popular and are replacing loop mechanics. However, a previous study² suggested that the friction generated between the archwire and brackets on the posterior teeth is progressively increased during space closure. This could in turn decrease the rate of tooth movement in the latter phase of space closure under sliding mechanics. In addition, the force system acting on each tooth is mechanically indeterminate due to the friction generated. Precise prediction of tooth movement and delivery of the optimal force system is therefore difficult in sliding mechanics.

On the other hand, loop mechanics involve a frictionless technique. Since 100% of the force generated by loops can be directly transmitted to the anterior teeth from the archwire, unlike sliding mechanics, this technique has the potential to produce preprogrammed moment-to-force (M/F) ratios for achieving the desired type of tooth movement.³

However, loop mechanics also show some disadvantages. That is, closing loops made of stainless steel wire could produce excessively heavy force, especially when gable bends are incorporated into the loop,⁴⁻⁶ and the M/F ratio produced by conventionally designed loops is too low to achieve controlled tipping or translation of anterior teeth⁷. Sumi et al. suggested that a simple design of a teardrop loop produced a gentle force even with a 0.021×0.025 -inch wire, and a high M/F ratio of 9.3 without adding a gable bend⁸. Nevertheless, an M/F ratio higher than 10 is required to achieve bodily movement or root movement for the correction of Class II, division 2 malocclusion.

The purpose of this study was to determine the mechanical conditions of the newly developed closing loop that can simultaneously produce the optimal magnitude of force and an M/F ratio higher than 10 using structural analysis. We investigated the effect on the force system generated at the loop ends of the amount of loop activation or the degree of gable bend incorporated into the loop with a partial reduction in its wire cross-section of a 0.017×0.025 -inch stainless steel archwire that is applicable in a 0.018-inch bracket slot system.

MATERIALS AND METHODS

The forces and moments acting on the ends of the closing loop were calculated by means of a computer program for geometric nonlinear analysis based on the tangent stiffness method, by which large deflection problems can be handled.⁹ The closing loop examined in this study was the teardrop type, which was 10 mm in height (Figure 1). The interbracket distance was set to be 10 mm. The loop was placed at a point 3 mm distal from the canine bracket (Figure 2), and was bent from a 0.017×0.025 -inch stainless steel archwire with Young's modulus of 200,000 MPa. The loop configuration was idealized by 57 elements. The loading steps were performed in the same manner as those described in previous studies.^{3,6} Forces and moments acting on both ends of the loop were calculated upon each application of various loading conditions.

In the first step, thickness of the cross-section of a closing loop was partially reduced by 0%, 10%, 20%, 30%, 40%, or 50% for a distance of 3 mm from the loop apex to investigate the effects of the rate of reduction in the wire cross-section on the force system.

In the second step, forces and moments generated at the loop ends (with a 50%

reduction in wire thickness) when increasing the amount of loop activation by 0, 0.5, 1, 1.5, and 2 mm were calculated to investigate the effect of the amount of loop activation on the force system.

In the third step, forces and moments acting on both ends of the loop, when varying the degree of gable bend from 0° to 50° at intervals of 10°, were calculated to determine the ideal loading condition for loop activation simultaneously producing the optimal force magnitude and M/F ratio for achieving controlled movement of the anterior teeth.

RESULTS

Figure 3 shows the forces, moments, and M/F ratios acting on the ends of a 10-mm-high teardrop loop for which the cross-section of 0.017×0.025 inches was reduced in thickness by 0%, 10%, 20%, 30%, 40%, and 50% for a distance of 3 mm from the apex with an activation of 1 mm. With reduction rates of 0%, 10%, 20%, 30%, 40%, and 50%, the retraction force was decreased from 256 g (no reduction in the wire cross-section) to 218, 183, 152, 127, and 106 g, respectively (Figure 3A). Similarly, the moment decreased from 1446 g/mm to 985 g/mm as the rate of reduction in the wire cross-section was increased from 0% to 50% (Figure 3B). The decreasing rate of force was much higher than that of the moment. On the other hand, the M/F ratio increased from 5.7 to 9.3 when the rate of reduction in the wire cross-section was increased from 0% to 50% (Figure 3C).

Figure 4 shows the forces, moments, and M/F ratios acting on the ends of the closing loop, when increasing the amount of loop activation from 0 to 2 mm in intervals of 0.5 mm. With the loop activation of 0, 0.5, 1, 1.5, and 2 mm, the force increased almost linearly from 0 to 53, 106, 160, and 216 g, respectively (Figure 4A). A similar tendency

was observed for the moment. The moment thus increased nearly linearly with increases in the rate of reduction of the wire cross-section (Figure 4B). Conversely, the M/F ratio decreased slightly but gradually from 9.5 to 8.7 as the amount of loop activation increased from 0.1 mm to 2 mm (Figure 4C).

Figure 5 shows the forces, moments, and M/F ratios acting on the ends of the closing loop with cross-section thickness reduced by 50% for a distance of 3 mm from the loop apex, when increasing the degree of gable bend from 0° to 50° in intervals of 10°. As the gable bend incorporated into the loop was increased from 0° to 50°, the force increased almost linearly from 106 g to 434 g (Figure 5A). Similarly, the moment increased from 985 g/mm to 4518 g/mm (Figure 5B).

With regard to the M/F ratio, with an increment in the degree of gable bend from 0° to 50°, increases from 9.3 to 10.4 were seen (Figure 5C). When the degree of gable bend was increased from 0° to 10°, the M/F ratio increased by 0.7. However, the rate of increment in the M/F ratio gradually decreased when the degree of gable bend was further increased from 10° to 50°.

DISCUSSION

There are mainly two types of mechanics used for space closure following tooth extraction in orthodontic treatments with fixed appliances: frictionless and friction techniques. The former is loop mechanics⁴ while the latter is sliding mechanics.^{10,11}

Both techniques have several advantages and disadvantages. Although the use of a plain archwire in sliding mechanics contributes to a reduction in chair time for orthodontists, and to the improvement of comfort and oral hygiene for the patient, a great amount of friction could decrease the rate of tooth movement during space

closure.¹¹ In addition, the force system acting on each tooth is mechanically indeterminate due to the friction generated. Accurate prediction of the movement pattern for each tooth is therefore difficult in sliding mechanics.^{11,12}

On the other hand, loop mechanics provide a frictionless technique, thereby delivering the preprogrammed force system for achieving the desired type of tooth movement without losing force.⁴ However, loop mechanics have the shortcoming of producing excessively heavy force, particularly when gable bends are incorporated into the loop,⁴⁻⁶ and the larger the wire size, the heavier the force produced. Another disadvantage of loop mechanics is that the M/F ratio generated by the conventional loop is too low to achieve controlled movement of the anterior teeth.^{4,6,7,13}

To increase the M/F ratio, many loop designs with complicated shapes have been developed by extending the horizontal length as well as the vertical height.¹³⁻¹⁵ Sumi et al. developed a simple design of a 10-mm-high teardrop loop,⁸ with the cross-section of 0.021×0.025 inches reduced in thickness by 50% for a distance of 3 mm from the apex. This newly designed closing loop produces a gentle force, even with a 0.021×0.025 -inch wire, and a higher M/F ratio of 9.3 without adding gable bends. Further advantages are that it is easily fabricated at chairside by grinding with a turbine handpiece and applicable in a 0.022-inch bracket slot system. However, previous articles have shown that an M/F ratio of at least 10 is required to achieve bodily movement, and 12 for root movement.^{16,17} According to these requirements, achieving bodily movement in a genuine manner or root movement might be difficult with the activation method and prescription of the previously developed loop,⁸ whose wire cross-section was partially reduced. In the present study, we investigated the proper mechanical and geometric conditions of activation of that specific design loop made of 0.017×0.025 -inch stainless

steel wire that can produce higher M/F ratio allowing bodily movement of the anterior teeth, and is applicable in the 0.018-inch bracket slot system.

When the reduction rate of the thickness of the 0.017×0.025 inch wire cross-section of the loop was increased from 0% to 50%, magnitudes of both force and moment generated from the loop decreased, while the M/F ratio increased. This is because the rate of decrease in the moment was much lower than that in the force (Figure 3). The greatest M/F ratio of 9.3 was produced with the reduction rate of 50%. However, this value did not exceed the ratio of 10 required to produce bodily movement.^{16,17} At this time, the magnitude of force was 106 g. Since this value was considered much lower than the desired force of 250 g for retraction of the anterior teeth,⁷ the force level was considered to require an increase either by increasing the amount of loop activation or by incorporating a gable bend into the loop.

In the next step, we investigated the effects of different amounts of loop activation on the force system, especially on the force magnitude. The forces, moments and M/F ratios acting on the ends of the loop were calculated when varying the amount of loop activation from 0 to 2 mm. The results showed that the magnitudes of force and moment increased as the amount of loop activation was increased (Figure 4). When the loop was activated by 2 mm, the force magnitude was 216 g, closer to the desired force for retracting the anterior teeth of 250 g.⁷ Conversely, the M/F ratio was decreased from 9.5 to 8.7 with increases in the amount of loop activation from 0 to 2 mm. Since bodily movement or root movement would not be achieved with the M/F ratios lower than 10, the amount of loop activation should not be increased to more than 1 mm in case the accomplishment of controlled anterior tooth movement is prioritized.

Another method used to increase the force magnitude as well as the M/F ratio is to

incorporate gable bends into closing loops, according to a previous study.⁶ As the degree of gable bend increased, force magnitude also increased (Figure 5A). Incorporation of gable bends of 20° to 30° into the loop was more likely to produce the optimal force level for anterior tooth retraction, since the ideal force magnitude for retraction of the anterior teeth is considered to be approximately 250 g.⁷ However, placement of a gable bend greater than 40° could generate excessively heavy force.

When a gable bend is incorporated into the loop (Figure 6A), which is then engaged in the brackets, junctions of the horizontal and vertical legs cross by distance “d” (Figure 6B) on the assumption that the loop has such a configuration that the contact between junctions could be avoided and pass each other. The loop in such an activated state would produce no force, although the moment is acting on both ends. This state is referred to as neutral activation, since the force magnitude is 0 g. The state of the activated loop, for which the junctions of the horizontal and vertical legs meet in the horizontal direction, is referred to as clinical activation of 0 mm (Figure 6C). Since both ends of the wire are activated by “d/2”, the traction force is produced at a clinical activation of 0 mm. Nevertheless, clinicians tend to think intuitively that no force is delivered when the distance between junctions of the horizontal and vertical legs of the loop is 0 mm, and further activate the loop more than necessary. This indicates that the more the gable bend is incorporated into the loop, the greater the force that will be generated beyond what clinicians might expect.⁴⁻⁶

The M/F ratio increased relatively rapidly from 9.3 to 10.0 when the degree of gable bend was increased from 0° to 10°, while the rate of increment in the M/F ratio gradually decreased as the degree of gable bend was further increased from 10° to 50° (Figure 5C). Even when the gable bend was increased from 10° to 50°, the M/F ratio was

increased only by 0.4. This is because the force increased linearly, while the rate of increment in the moment decreased as the degree of gable bend was increased.

Placement of a gable bend of 20° to 30° into the loop is suggested to be appropriate for delivering the optimal force magnitude and M/F ratio for achieving controlled movements, such as bodily movement of the anterior teeth. On the other hand, a gable bend angle greater than 40° should not be incorporated into the loop, since such an excessive degree of gable bend would not produce a sufficiently high M/F ratio, while delivering markedly heavy force that could damage the incisors and surrounding periodontal tissues as a side effect.

Although a gable bend of 20° to 30° could produce the M/F ratio of 10.2 to 10.3, thereby achieving bodily movement of the anterior teeth, this value is insufficient to achieve root movement for the correction of Class II, division 2 malocclusion, which requires an M/F ratio ≥ 12 .^{16,17} Burstone and Koenig⁴ reported that the vertical height of the loop is the dominant factor influencing the M/F ratio, and the higher the loop, the greater the M/F ratio. Root movement could be achieved by lengthening the loop height from 10 to 11 or 12 mm if the gingivobuccal fold is deep enough.

Further studies are necessary to clarify the effects of vertical and horizontal lengths of different loop designs on the force system, and to develop a new design for a closing loop that produces a much higher M/F ratio.

CONCLUSIONS

The optimal force magnitude and M/F ratio for achieving controlled movement such as bodily movement of the anterior teeth can be produced simply by reducing the thickness of the wire cross-section of a 0.017 × 0.025-inch teardrop loop of 10 mm in height by 50%

for a distance of 3 mm from the apex, and by placing a gable bend of 20° to 30° in the 0.018-inch bracket slot system.

REFERENCES

1. Tweed CH. The application of the principles of the edgewise arch in the treatment of malocclusions: II. Angle Orthod 1941;11:12-67.
2. Hamanaka R, Yamaoka S, Anh TN, Tominaga JY, Koga Y, et al. Numeric simulation model for long-term orthodontic tooth movement with contact boundary conditions using the finite element method. Am J Orthod Dentofacial Orthop 2017;152:601-12.
3. Chiang PG, Koga Y, Tominaga J, Ozaki H, Hamanaka R, Sumi M, et al. Effect of gable bend incorporated into loop mechanics on anterior tooth movement: comparative study between en masse retraction and two-step retraction. Orthod Waves 2015;74:55-61.
4. Burstone CJ, Koenig HA. Optimizing anterior and canine retraction. Am J Orthod 1976;70:1-19.
5. Braun S, Gaecia JL. The gable bend revisited. Am J Orthod Dentofacial Orthop 2002;122:523-7.
6. Yoshida N, Jost-Brinkmann PG, Koga Y, Kobayashi K, Obiya H, Peng CL. Moment/Kraft-Verhältnisse von Kontraktionsbögen während Deaktivierung. Kieferorthop 2004;18:175-82.
7. Proffit WR. Closure of extraction space. In: Proffit WR, Fields HW, Sarver DM, editors. Contemporary orthodontics. 4th ed. St Louis: Mosby Elsevier; 2007. p. 592-601.
8. Sumi M, Koga Y, Tominaga J, Hamanaka R, Ozaki H, Chinag PG, et al. Innovative

- design of closing loops producing an optimal force system applicable in the 0.022-in bracket slot system. *Am J Orthod Dentofacial Orthop* 2016;150:968-78.
9. Iguchi S, Goto S, Iijima K, Obiya H. Folding analysis of reversal arch by the tangent stiffness method. *Struct Eng Mech* 2001;11:211-9.
 10. McLaughlin RP, Bennett JC. The transition from standard edgewise to preadjusted appliance systems. *J Clin Orthod* 1989;23:142-53.
 11. Nanda R, Ghosh J. Biomechanical considerations in sliding mechanics. In: Nanda R, editor. *Biomechanics in Clinical Orthodontics*. Philadelphia: W. B. Saunders Co., 1997. p. 188-217.
 12. Tominaga J, Ozaki H, Chiang PG, Sumi M, Tanaka M, Koga Y, et al. Effect of bracket slot and archwire dimensions on anterior tooth movement during space closure in sliding mechanics: a 3-dimensional finite element study. *Am J Orthod Dentofacial Orthop* 2014;146:166-74.
 13. Siatkowski RE. Continuous arch wire closing loop design, optimization, and verification. Part 1. *Am J Orthod Dentofacial Orthop* 1997;112:393-402.
 14. Burstone CJ. The segmental arch approach to space closure. *Am J Orthod Dentofacial Orthop* 1982;82:362-78.
 15. Kuhlberg AJ, Burstone CJ. T-loop position and anchorage control. *Am J Orthod Dentofacial Orthop* 1997;112:12-8.
 16. Nanda R, Gosh J. Principles of biomechanics. In: Nanda R, editor. *Biomechanics in clinical orthodontics*. Philadelphia: Saunders; 1997. p. 6-8.
 17. Burstone CJ, van Steenberg E, Hanley KJ. *Modern edgewise mechanics and the segmented arch technique*. Farmington, Conn: Ormco; 1995.

LEGENDS

Figure 1. A 10-mm-high teardrop loop with the wire cross-section reduced for a distance of 3 mm from the loop apex.

Figure 2. Schematic representation of the loop located 3 mm distal from the canine bracket. The interbracket distance is 10 mm.

Figure 3. Forces (A), moments (B), and M/F ratios (C) generated by the closing loop associated with reduction of the wire cross-section by 0%, 10%, 20%, 30%, 40%, and 50%.

Figure 4. Forces (A), moments (B), and M/F ratios (C) generated by the closing loop associated with loop activation by 0, 0.1, 0.5, 1, 1.5, and 2 mm.

Figure 5. Forces (A), moments (B), and M/F ratios (C) generated by the closing loop associated with gable bend of 10°, 20°, 30°, 40°, and 50°.

Figure 6. Activation of a loop into which a gable bend is incorporated. **A)** Before insertion into the brackets. **B)** Neutral activation. When a loop with a gable bend is engaged in the brackets, junctions of the horizontal and vertical legs cross by “d”. **C)** Clinical activation of 0 mm, wherein the distance between junctions of horizontal and vertical legs of the loop is 0 mm, although both ends of the wire are activated by “d/2”.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6