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Original article

Effect of gable bend incorporated into loop mechanics on anterior tooth movement: Comparative study between en masse retraction and two-step retraction

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ABSTRACT

Purpose: To verify whether en masse retraction or two-step retraction could provide more effective torque control of the anterior teeth when varying the degree of gable bend in loop mechanics.
Materials and methods: The forces and moments delivered by 10 mm high teardrop loops with gable bends of 0, 5, 10, 15, 20, 25, and 30° were calculated by the tangent stiffness method and applied to three-dimensional (3D) finite element (FE) models. FE models simulating en masse retraction and two-step retraction were constructed separately. The movement patterns of the maxillary central incisor, namely the degree of lingual crown tipping and the location of the center of rotation (CRo), were analyzed.
Results: The moment to force (M/F) ratio generated by activation of closing loops increased as the degree of gable bend was increased from 0 to 30°. The degree of lingual crown tipping increased in en masse retraction, whereas it decreased in two-step retraction as the degree of gable bend was increased. Although the location of the CRo remained almost at the same position in en masse retraction, it moved apically in two-step retraction when increasing the degree of gable bend.
Conclusion: Incorporation of gable bends into closing loops would provide effective torque control of the anterior tooth in two-step retraction. Conversely, it is considered that the movement patterns of anterior teeth are hardly influenced by gable bends placed into loops in en masse retraction.

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1. Introduction

Closing loops have been widely used for space closure in the treatment of four premolar extraction cases ever since the Tweed technique was established [1,2]. Since loop mechanics is a frictionless technique, 100% of the force generated by loops can be directly transmitted to each tooth from the archwire without losing force or moment, unlike sliding mechanics, which generate binding of the archwire in the bracket slots due to friction in the course of treatment [3]. Moreover, this technique has the potential to produce preprogrammed moment to force (M/F) ratios for achieving the desired type of tooth movement by incorporating gable bends into closing loops [4]. Treatment mechanics for space closure have mostly changed from loop mechanics to sliding mechanics in recent years due to its simplicity, improved patient comfort and reduced chair time, and as it is more applicable in combination with temporary anchorage devices. However, loop mechanics is still considered a much more efficient technique for controlling the position of the center of rotation (CRo), namely, the type of tooth movement by providing appropriate M/F ratios from the perspective of biomechanics.

There are two mainstream methods of anterior teeth retraction in loop mechanics. One is en masse retraction, in which six anterior teeth are retracted all at once. The other is two-step retraction, which includes a single canine retraction followed by retraction of four incisors. However, to date, a clear distinction between indications of en masse retraction and two-step retraction has not been established. Although many studies analyzed the force systems acting on the tooth during the activation of closing loops experimentally [4–6] or analytically [7,8], there have been very few attempts focusing on the resultant tooth movement. The aim of this study was thus to clarify the different effects of gable bends in loop mechanics on anterior tooth movement during en masse retraction and two-step retraction by means of the finite element (FE) method in combination with large deflection analyses based on tangent stiffness method.

2. Materials and methods

2.1. Tangent stiffness method

The forces and moments acting on the ends of closing loops associated with various degrees of gable bend (0, 5, 10, 15, 20, 25, and 30°) were calculated by means of a structural analysis based on the tangent stiffness method, in which large deflection can be handled [9]. The closing loop examined in this study was the teardrop type, which was 10 mm in height. The interbracket distance was 14 mm, and the loop was set in the centered position and was bent from a 0.017 × 0.022-in stainless steel archwire with Young's modulus of 200,000 MPa. The teardrop loop was idealized by 62 elements. Analysis of the loop is performed in two load steps. In case the gable bend of θ degree is given to the loop, forced rotation of $\theta/2$ is given to both ends. Then forced displacements of 1.0 mm are given to both ends, at which the model was restrained by all translations and rotations. Forces and moments acting on both ends of the loop were calculated upon each application of above-mentioned boundary conditions.

2.2. Three-dimensional (3D) FE model and material parameters

A multi-image cone beam computed tomography (CT) scanner (3DX, J. Morita, Kyoto, Japan), was used to take images of the maxillary dentition (left side only). The CT images were saved and converted to a 3D FE model using FE analysis pre- and postprocessor software (Patran 2013 64 bit, MSC Software Corp, Los Angeles, CA, USA). The details of the procedure have been described in previous articles [10,11]. Each 3D FE model for periodontal ligament (PDL), alveolar bone, bracket, and archwire were separately constructed using the same software. Thickness of the PDL was determined to be a uniform 0.2 mm and the material parameters used in this study are shown in Table 1 as stated in previous studies [12,13].

An appliance with 0.018-in bracket slots and a 0.017 × 0.022-in stainless steel archwire was generated to simulate the actual clinical situation. The 3D FE models consisted of 37,454 nodes and 189,595 elements or 33,690 nodes and 169,676 elements in the en masse retraction model and the two-step retraction model, respectively (Fig. 1).

2.3. Experimental conditions

The en masse retraction model was created based on the assumption that all six anterior teeth were retracted at one time by loop mechanics for a bilateral first-premolar extraction case. On the other hand, the two-step retraction model was reconstructed for simulating retraction of four incisors by loop mechanics after a single canine retraction.

The force systems calculated by the tangent stiffness method were applied to the points on the archwire corresponding to the ends of the brackets next to the extraction space (the distal end of the canine's bracket and the mesial end of the second premolar's bracket in the en masse retraction model or the distal end of the lateral incisor's bracket and the mesial end of the canine's bracket in the two-step retraction model) on the 3D FE model of the maxillary dentition. The displacement analyses were performed using a 3D FE program (Marc, MSC Software Corp, Los Angeles, CA, USA).

2.4. Evaluation of movement pattern of maxillary central incisor

To scientifically evaluate the effect of changes in the angle of gable bend on the movement patterns of anterior teeth, the

Table 1 – Material parameters of tooth, PDL[a], Alveolar Bone, Archwire, and Bracket.

Material	Young's modulus (MPa)	Poisson's ratio
Tooth	20,000	0.30
PDL	0.05	0.30
Alveolar bone	2000	0.30
Archwire/Bracket	200,000	0.30

[a] PDL indicates periodontal ligament.

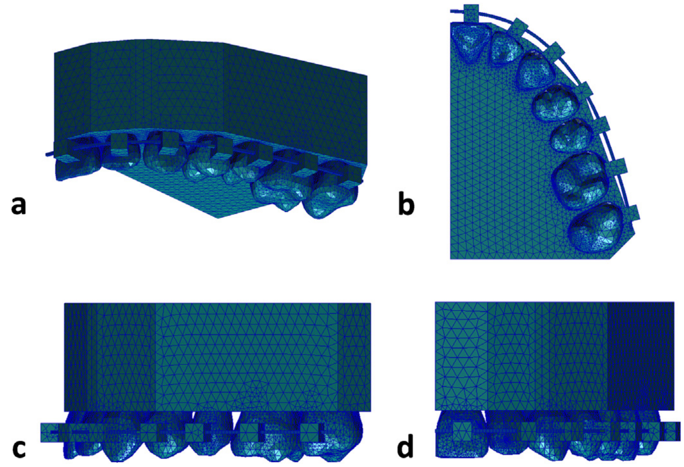

Fig. 1 – 3D finite element model of the maxillary dentition (left side) including PDL, alveolar bone, brackets and archwire. (a) Oblique view, (b) occlusal view, (c) lateral view and (d) frontal view.

degree of lingual crown tipping movement and the position of CRo of the maxillary central incisor were calculated. Fig. 2 illustrates the lingual crown tipping angle and the position of CRo of maxillary central incisor analyzed in this study. Although there are several definitions of CRo, a concept defined by Burstone [14], wherein the CRo is the intersection of two lines coincident with the extensions of the tooth axis before and after displacement, was applied in this calculation.

3. Results

The magnitudes of force and moment generated at the ends of a teardrop loop 10 mm in height with various degrees of gable bends on activation of 1 mm are shown in Fig. 3. The retraction force and the moment almost linearly increased from 185 to 541 gf, and from 577 to 2603 gf-mm, respectively, as the degree of gable bend increased from 0 to 30°. The calculated M/F ratio increased from 3.12 to 4.82 mm as gable bend angle increased from 0 to 30° (Fig. 4).

When forces and moments obtained from a structural analysis based on the tangent stiffness method were applied to 3D FE models, quite different movement patterns of the maxillary central incisor were observed between the two models. Fig. 5 shows examples of the movement patterns of the maxillary central incisor when gable bends of 30° were placed into loops. The incisor showed uncontrolled tipping during en masse retraction (Fig. 5a, 10 times magnification for clear demonstration). In contrast, controlled tipping was observed in the two-step retraction model (Fig. 5b).

In the en masse retraction model, the lingual crown tipping angle of maxillary central incisor increased from 0.44 to 1.06° with varying degrees of gable bend from 0 to 30° (Fig. 6). On the other hand, in the two-step retraction model, the degree of lingual crown tipping angle decreased from 0.14 to 0.03° as the gable bend angle was increased from 0° to 30°.

Fig. 7 shows the calculated locations of CRo of the maxillary central incisor caused by changes in the degree of gable bend in the en masse retraction model. In this simulation, the location of CRo remained almost at the same position while gable bend angle increases from 0 to 30°. In contrast, the position of CRo moved apically with the distance increasing exponentially as the gable bend angle was increased in the two-step retraction model (Fig. 8). When a gable bend angle of 30° was placed into a loop, the CRo was located on the apical side even far from the root apex.

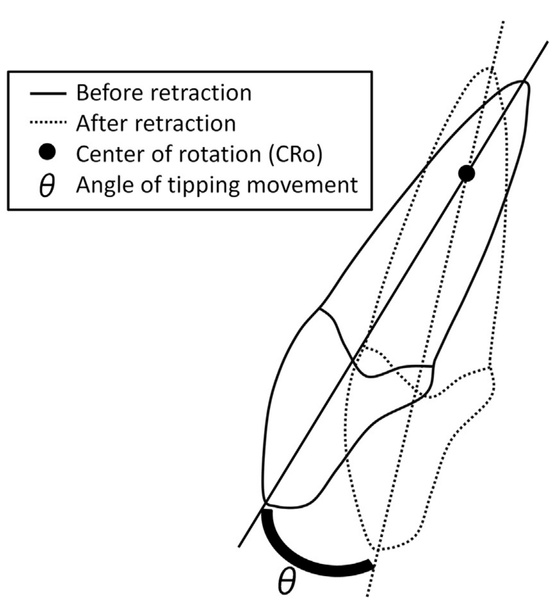

Fig. 2 – Definition of the angle of tipping movement (θ) and the point of the CRo of the maxillary central incisor during retraction.

4. Discussion

En masse retraction and two-step retraction have been mostly employed in loop mechanics; however, there is no clear scientific evidence to verify which method is more efficient

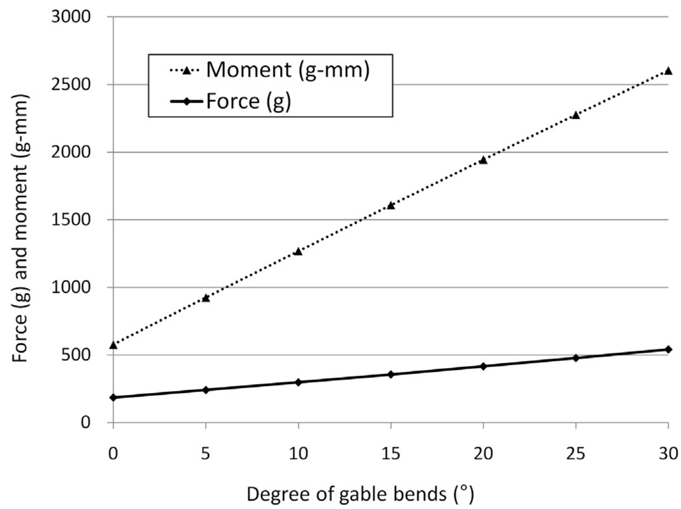

Fig. 3 – Forces and moments generated at ends of closing loops with varying degrees of gable bend from 0 to 30° at an interval of 5°.

way to achieve controlled movement of the anterior teeth. For this reason, in the present study, these two treatment mechanics were compared focusing on the anterior tooth movement during retraction using numerical methods.

In this study, we used two steps of numerical analyses. That is, as the first step, the force systems generated at both ends of closing loops associated with various degrees of gable bend were calculated by tangent stiffness method. The tangent stiffness method can accurately handle large displacement phenomena of frame structures in space due to the element translating as a rigid body without dividing the structure into very fine elements [9]. On the other hand, application of the FE method is inappropriate for structural analyses of loops which are largely deformed [15]. This is because the quality of results obtained from FE method depends on the discretization in space and time; therefore errors would be anticipated especially in large deflection analysis. For this reason, the tangent stiffness method was employed in the first step of analyses. In the second step, forces and moments developed on the ends of closing loops were applied to the points on the archwire corresponding to the ends of the brackets next to the extraction space on the 3D FE model of the maxillary dentition. Consequently, this study suggested a new simulation method by means of FE model integrated with large deformation analysis based on the tangent stiffness method to precisely analyze the movement of maxillary central incisor during retraction with loop mechanics.

The retraction force and moment delivered by a teardrop loop were almost proportionally increased with an increment in the degree of gable bend (Fig. 3). In regards to M/F ratio, it was found that this value also rises as the degree of gable bend is increased (Fig. 4), since the rate of increment in moment is much higher than that in force associated with varying gable bend from 0 to 30°. Although the concept of optimal force remains obscure [16,17], the ideal force magnitude for retraction of the anterior teeth is considered to be approximately 3.10 N [18]. The present study showed that a 10 mm-teardrop loop with a gable bend over 30° would deliver more than 541 gf. Since the placement of an excessively high degree of gable bend in the loop would deliver a markedly heavy force that could cause damage to the maxillary incisors and the surrounding periodontal tissues, the degree of gable bend must be reduced to less than 30° to avoid deleterious effects on

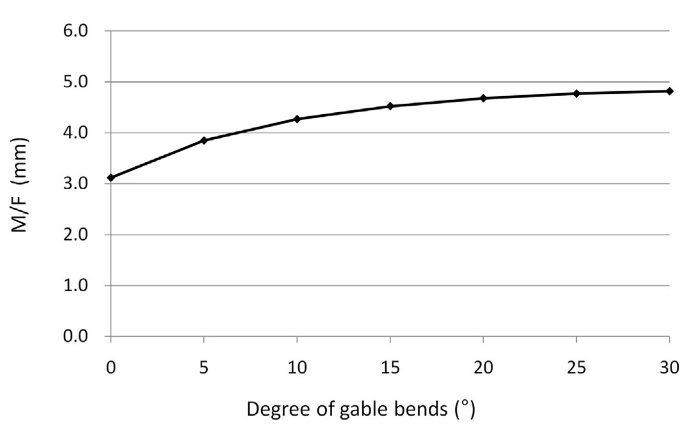

Fig. 4 – M/F ratios generated at ends of closing loops with varying degrees of gable bend from 0 to 30° at an interval of 5°.

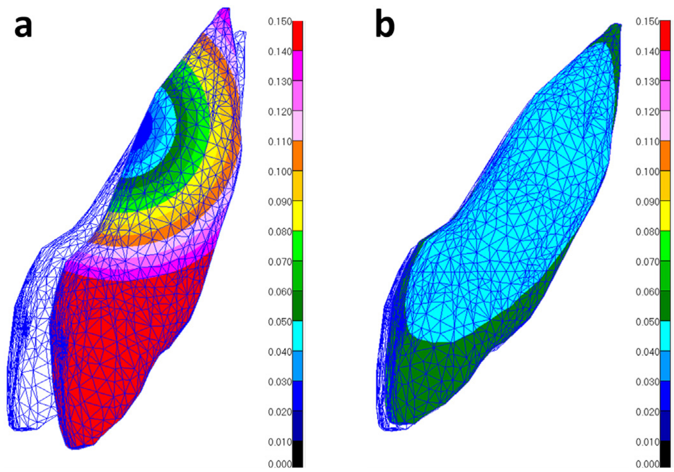

Fig. 5 – Displacement of the maxillary central incisor with gable bend of 30° analyzed by means of FE method. (a) En masse retraction model and (b) two-step retraction model (Magnification rate: 10 times).

teeth or it is recommended to reduce the amount of activation of the loops for decreasing the retraction force.

In the en masse retraction model, the maxillary central incisor showed uncontrolled tipping, in which the incisal edge is retracted, but the root apex is displaced in the opposite direction, even if gable bends of 30° were given (Fig. 5a). In contrast, controlled tipping, in which the incisor tips around the root apex or a point apically to it as a rotation axis, was observed in two-step retraction model when gable bends of 30° were applied (Fig. 5b). These results suggest that uncontrolled tipping may be prevented by placing gable bends into a loop in two-step retraction, but cannot be avoided in en masse retraction.

To quantitatively evaluate the effect of changes in the angle of gable bend on the tipping tendency of the maxillary central incisor, the degree of lingual crown tipping movement was calculated. In the en masse retraction model, when a higher degree of gable bend was placed in a loop, lingual crown tipping occurred more substantially (Fig. 6). It is considered that the increase in the gable bend angle in en masse retraction would only strengthen the retraction force, but not contribute to achieving controlled movement of the anterior teeth. Contrarily, in the two-step retraction model, the degree of lingual crown tipping decreased as the degree of gable bend was increased. This indicates that the placement of gable bend in a loop could provide more effective torque control of the anterior teeth in two-step retraction than in en masse retraction.

In order to compare the movement pattern of the maxillary central incisor in en masse retraction with that in two-step retraction, we calculated the location of the CRo, which could simply and precisely express the type of tooth movement [14,19]. In the en masse retraction model, even if the angle of gable bend was increased, the location of CRo remained almost at the same position (Fig. 7). In contrast, in the two-step retraction model, the location of CRo was displaced almost

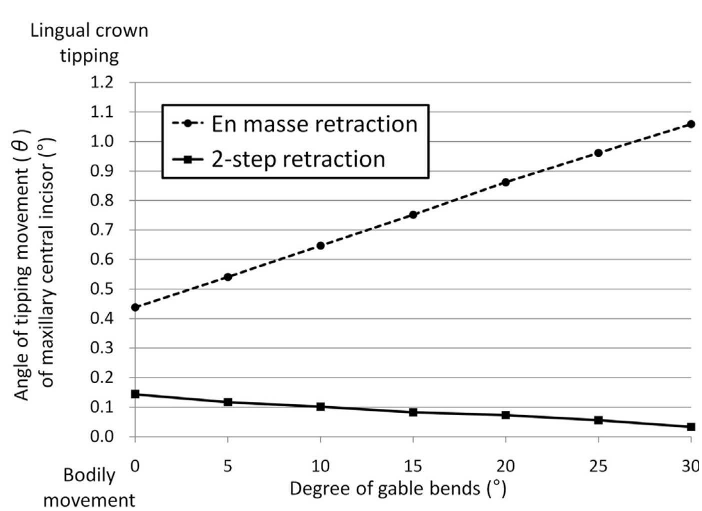

Fig. 6 – Degree of lingual crown tipping of the maxillary central incisor with different degrees of gable bends during en masse retraction and two-step retraction.

	Gable bend angle	Center of rotation (X, Y)
□	0°	(1.08, 1.79)
◇	5°	(1.10, 1.82)
△	10°	(1.10, 1.83)
×	15°	(1.10, 1.84)
−	20°	(1.12, 1.85)
+	25°	(1.12, 1.86)
○	30°	(1.12, 1.86)
◆	CRe	(0, 0)

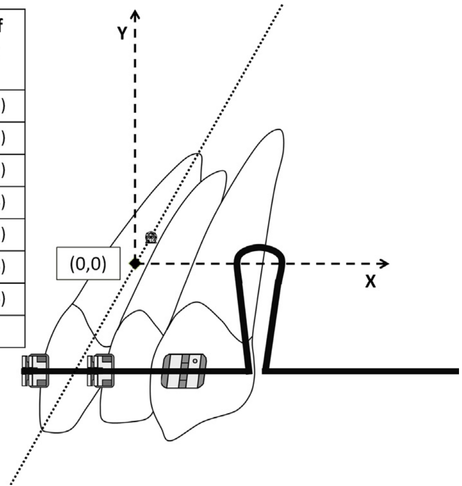

Fig. 7 – Locations of CRo of the maxillary central incisor during en masse retraction with different degrees of gable bends (shown in coordinate values as CRe is the origin).

	Gable bend angle	Center of rotation (X, Y)
■	0°	(1.45, 2.45)
◆	5°	(1.91, 3.27)
▲	10°	(2.36, 4.08)
×	15°	(2.98, 5.18)
−	20°	(3.92, 6.86)
+	25°	(5.67, 9.98)
●	30°	(9.75, 17.28)
◇	CRe	(0, 0)

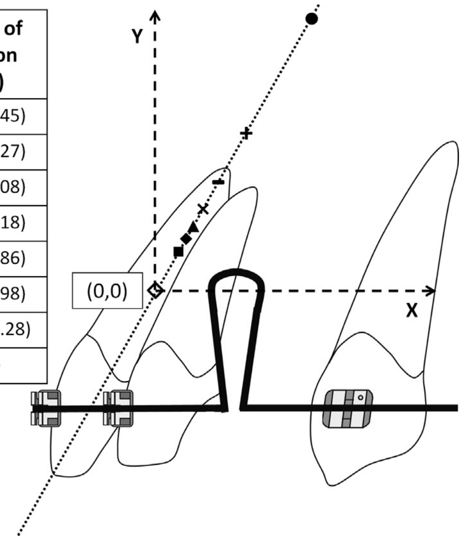

Fig. 8 – Locations of CRo of the maxillary central incisor during two-step retraction with different degrees of gable bends (shown in coordinate values as CRe is the origin).

exponentially in the apical direction as the degree of gable bend was increased (Fig. 8). When no gable bend was given to a loop in two-step retraction, the CRo was located approximately at the center of the root similarly to the case of en masse retraction. Uncontrolled tipping is likely to occur in en masse retraction regardless of whether or not a gable bend is incorporated, or in two-step retraction without a gable bend. On the other hand, the placement of a gable bend of 20° located the CRo near the root apex, which would produce controlled tipping. By increasing the degree of gable bend to more than 25°, the CRo moved further apically beyond the root apex. If the angle of the gable bend exceeds 30°, the CRo could possibly shift further to infinity, which indicates that the type of tooth movement would approach translation or bodily movement. This analysis suggests that the anterior teeth movement becomes more and more controllable as the degree of gable bend is increased in two-step retraction.

Results obtained from the en masse retraction model indicated that M/F ratios generated by gable bends are not effectively transmitted to the central incisor when loops are placed distal to the canines. It is because the maxillary canine teeth with large roots in the dentition might absorb greater part of the force systems generated by loops with gable bends. Conversely, incorporation of closing loops into the archwire between lateral incisors and canine teeth in the two-step retraction technique might have a greater impact on applying effective torque, thereby providing better control of the anterior teeth than in en masse retraction.

Nevertheless, the en masse retraction method has replaced two-step retraction as it enables clinicians to perform more efficient space closure and shorten the total treatment time [20,21]. If the en masse retraction technique is employed in loop mechanics, a certain degree of twist should be placed in the anterior portion of the archwire for applying additional torquing force, which would result in better control of anterior tooth movement.

5. Conclusions

- In two-step retraction, gable bends might have a greater impact on applying effective torque, thereby providing better control of anterior tooth movement than in en masse retraction.
- In en masse retraction, incorporation of gable bends into closing loops is totally ineffective for applying torque to the anterior teeth. Additional torque application by placing a twist in the anterior portion of the archwire would be necessary for achieving better control of the anterior tooth movement.

Conflict of interest

The authors declare that there are no conflicts of interest.

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