Original Article

Finite element study of controlling factors of anterior intrusion and torque during Temporary Skeletal Anchorage Device (TSAD) dependent en masse retraction without posterior appliances: *Biocreative hybrid retractor (CH-retractor)*

Sung-Seo Mo[a]; Min-Ki Noh[b]; Seong-Hun Kim[c]; Kyu-Rhim Chung[d]; Gerald Nelson[e]

ABSTRACT

Objectives: To evaluate, using the finite element method (FEM), the factors that allow control of the anterior teeth during en masse retraction with the Biocreative hybrid retractor (CH-retractor) using different sizes of nickel-titanium (NiTi) archwires and various gable bends on the stainless-steel (SS) archwires.

Materials and Methods: Using FEM, the anterior archwire section, engaged on the anterior dentition, was modeled in NiTi, and another assembly, the posterior guiding archwire, was modeled in SS. Two dimensions (0.016×0.022- and 0.017×0.025-inch NiTi) of the anterior archwires and different degrees (0°, 15°, 30°, 45°, and 60°) of the gable bends on the guiding wire were applied to the CH-retractor on the anterior segment to evaluate torque and intrusion with 100-g retraction force to TSADs. Finite element analysis permitted sophisticated analysis of anterior tooth displacement.

Results: With a 0° gable bend all anterior teeth experienced extrusion. The canines showed a larger amount of extrusion than did the central and lateral incisors. With a gable bend of $>$15°, all anterior teeth exhibited intrusion. Bodily movement of the central incisor required a 30°$\sim$45° gable bend when using anterior segments of 0.016×0.022-inch NiTi and 15°$\sim$30° gable bend with the 0.017×0.025-inch NiTi.

Conclusions: With the CH-retractor, varying the size of the NiTi archwire and/or varying the amount of gable bend on the SS archwire affects control of the anterior teeth during en masse retraction without a posterior appliance. (*Angle Orthod.* 2020;90:255–262.)

KEY WORDS: En masse retraction; Biocreative orthodontic strategy; FEA; TSAD; NiTi; Torque; Gable bend

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INTRODUCTION

Many dentoalveolar protrusion patients have Class I or II molar relationships with good and stable interdigitation of the posterior teeth. When fixed appliances are placed on these posterior teeth, the occlusion is inevitably altered, sometimes unfavorably. In the extraction protocol of the "Biocreative Orthodontic Strategy," the maxillary anterior teeth are effectively retracted without any orthodontic appliances on the posterior teeth during retraction.[1,2]

Biocreative therapy using conventional C-wires (previously reported 0.016×0.022-inch stainless-steel [SS] retraction arch on the anterior teeth, with traction from the partially osseointegrated C-implant[3]) has many advantages, such as low friction and reduced periodontal challenge to the posterior teeth, with no impact on the normal posterior occlusion. Bodily

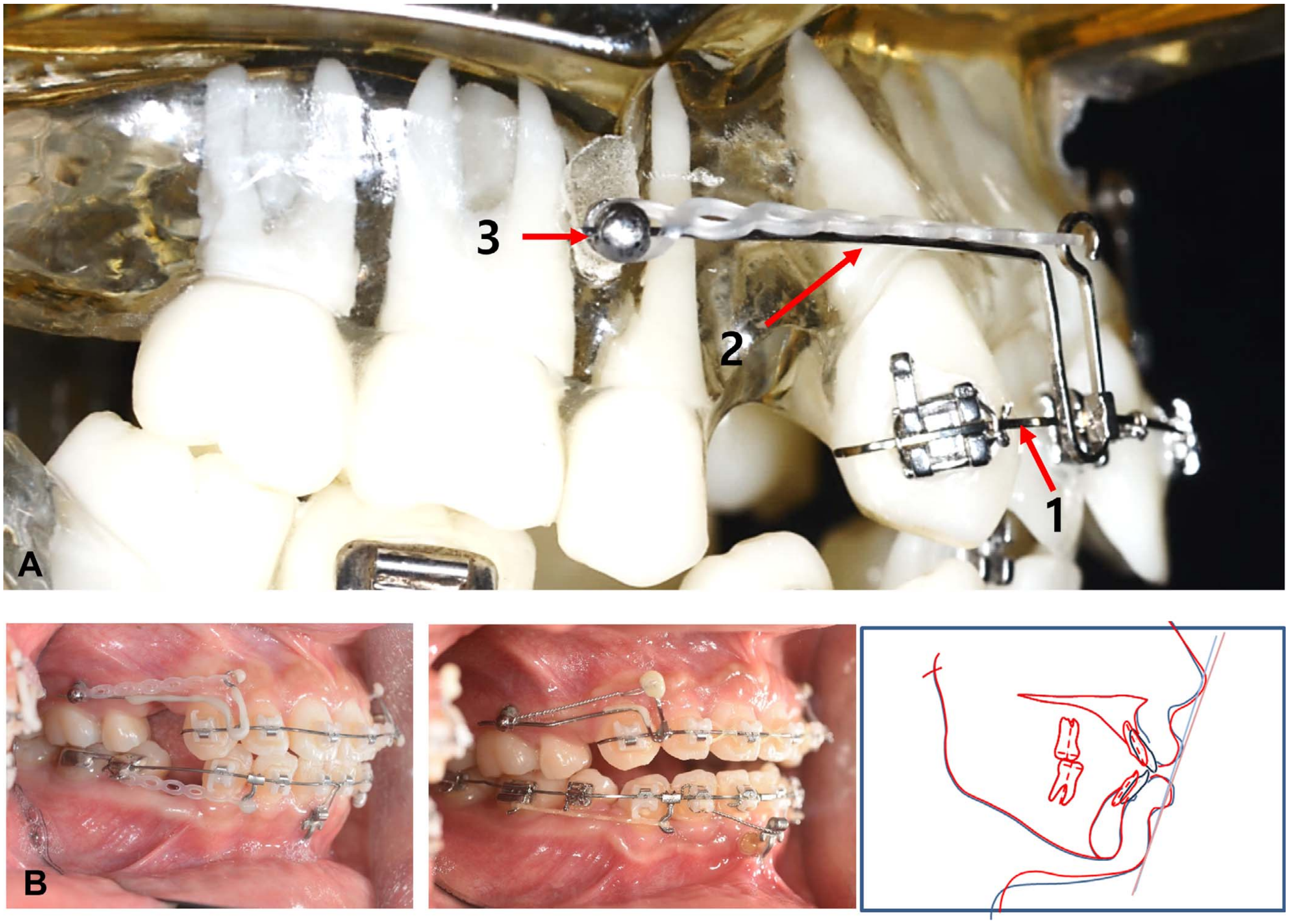

Figure 1. (A) Composition of CH-retractor: (1) Anterior archwire (0.016 × 0.022- or 0.017 × 0.025-inch NiTi); (2) Posterior archwire (0.017 × 0.025-inch SS); (3) Osseointegrated mini-implant (C-implant). (B) Pre and post–CH-retractor application with gable bends and superimposition (13-year-old male patient).

translation of the incisors is achieved with a combination of intrusion and retraction forces rather than the archwire-bracket interface. Extra training regarding the placement of steps and bends in the SS archwires may be required of clinicians to properly engage crowded and unleveled anterior teeth.[3–7] The high load-deflection rate of conventional SS C-wires necessitates regular and sometimes tedious archwire adjustments at each visit, increasing chairside time. To overcome these shortcomings, the Biocreative hybrid retractor (CH-retractor) assembly of an anterior nickel-titanium (NiTi) section and posterior SS archwire sections, as shown in Figure 1, was designed.[5,6] The NiTi section engages the maxillary anterior teeth (canine to canine) despite a crowded and unleveled condition. The posterior components are the SS archwire segments, which apply the force level and vector to retract the anterior teeth. The partially osseointegrated C-implants or C-tube miniplates are the exclusive source of anchorage; the posterior teeth have no orthodontic attachments.

In a previous study,[8] the clinical efficiency of the preformed SS C-wire was reported for the treatment of dentoalveolar protrusion patients who have stable Class I molar relationships. With the CH-retractor, simultaneous alignment, leveling, and space closure are possible from the day appliances are placed. Typically, one archwire is needed for the entire space closure phase of treatment. For crowded teeth (eg, lingually blocked lateral incisors), the NiTi archwire is ligated to central incisors and canines, and light distal forces are applied to canines to make room for the lateral incisors. Concurrently, the lateral incisors are repeatedly and gently tied to the archwire with steel ligature until they also adapt to the archwire. This way, retraction of the anterior teeth begins at the very first bonding appointment. Retraction force with torque and vertical control is easily applied without unnecessary

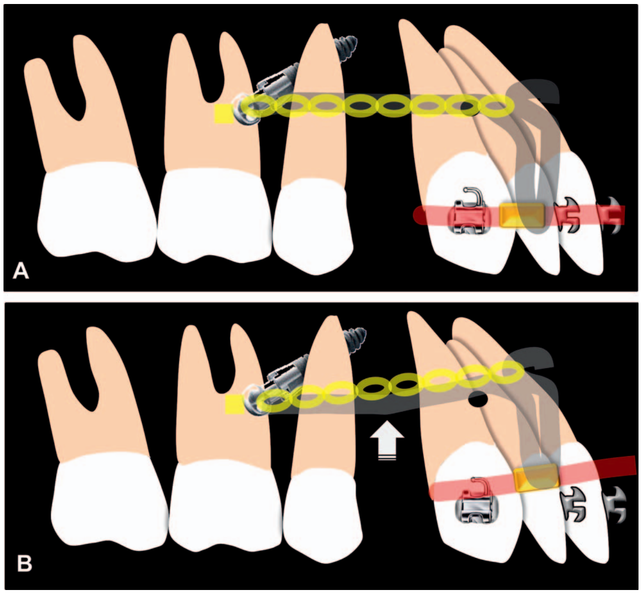

Figure 2. Illustration of CH-retractor. Anterior NiTi wire (0.016 × 0.022 or 0.017 × 0.025), posterior guiding wire (0.017 × 0.025 SS). (A) Without gable bend model; (B) With gable bend model: An intrusive force on the incisor bracket by gable bends applied to the main archwire combined with a retraction force will produce a torquing moment, and it is called "Biocreative Type I torque control mechanics."

anchor loss. Posterior teeth, which are not part of the appliances, are not disturbed.

The factors controlling anterior torque during en masse retraction with conventional C-wire were studied with finite element analysis.[9] Conventional SS C-wire resembles a utility archwire engaged only on the anterior teeth (the target teeth of the CH-retractor system) and extended posteriorly into the hole of the C-implant. In the previous study, different heights of retraction hooks and different angles of gable bends on the archwire affected the lingual root torque applied to the incisors.

In contrast to the conventional SS C-wire, the CH-retractor is an assembly of NiTi and SS archwires (Figure 1). A significant difference in the biomechanical controlling factors would be expected between the two types of wires. The NiTi archwire could be deflected to produce incisor intrusion forces by the moment induced from a gable bend on the SS archwire (Figure 2). To gauge the correct archwire sizes and adjustments of the archwires, a study was designed to standardize the factors that control the anterior torque and intrusion. The aim of this study was to evaluate the factors controlling upper anterior retraction during TSADs-dependent en masse retraction with the CH-retractor and no posterior appliances using finite element analysis. The hypothesis of this study was that different gable bends on the CH-retractor could be used to control the anterior torque effectively.

Table 1. Mechanical Properties of Each Material

	Young's Modulus, MPa	Poisson's Ratio
Teeth	2.0E+04	0.3
Bracket	2.0E+05	0.3
Periodontal ligament	5.0E-02	0.3
Alveolar bone	2.0E+03	0.3
Nickel-titanium wire	1.2E+05	0.3
Stainless-steel wire	2.0E+05	0.3

MATERIALS AND METHODS

The outline of tooth shape was obtained with three-dimensional laser scanning of the maxillary right-side teeth from a dental study model (model-i21D-400G; Nissin Dental Products, Kyoto, Japan) with normal occlusion. All teeth were aligned and leveled into a broad arch form (Ormco, Glendora, Calif) on the basis of the studies of Andrews,[10] Germane et al.,[11] and Park and Yang[12] for inclinations and angulations. Curve of Spee or a curve of Wilson (Figure 3A) was not added. The thickness of the Periodontal Ligament (PDL) was assumed to be uniform (0.25 mm) on the basis of the studies of Coolidge[13] and Kronfeld[14] (Figure 3B). The alveolar bone crest was designed to follow the curvature of the cemento-enamel junction, 1 mm apical to it.[15] The three-dimensional finite element model (FEM) consisted of 12 teeth, empty space according to the missing first premolars, periodontal space, and alveolar bone. The model was bilaterally symmetrical. The distance from the incisal edge of the central incisor to the bracket slot (perpendicular to the occlusal plane) was 4.5 mm.

Teeth, brackets, alveolar bones, periodontal ligament, and the C-implant in the FEM were constructed with fine tetrahedron solid elements. In this study, teeth, alveolar bones, and periodontal spaces were assumed to be isotropic and homogeneous linear elastic bodies. The material properties of the elements followed Young's modulus and Poisson's ratio according to the studies of Tanne et al.,[16] Poppe et al.,[17] and Ziegler et al.[18] (Table 1). For the coordinate system, the x-axis was the in-out direction, the y-axis the labiolingual direction, the z-axis the upper-lower direction, +x was the right central incisor direction, +y was the anterior direction, +z was the apical direction, and the x-y plane was the occlusal plane of the teeth (Figure 3C,D). The two main archwires were designed by a three-dimensional beam element (ANSYS beam 4, Swanson Analysis System, Canonsburg, Pa) with a 0.016 × 0.022- and a 0.017 × 0.025-inch NiTi. The anterior retraction hook (ARH) was positioned on the

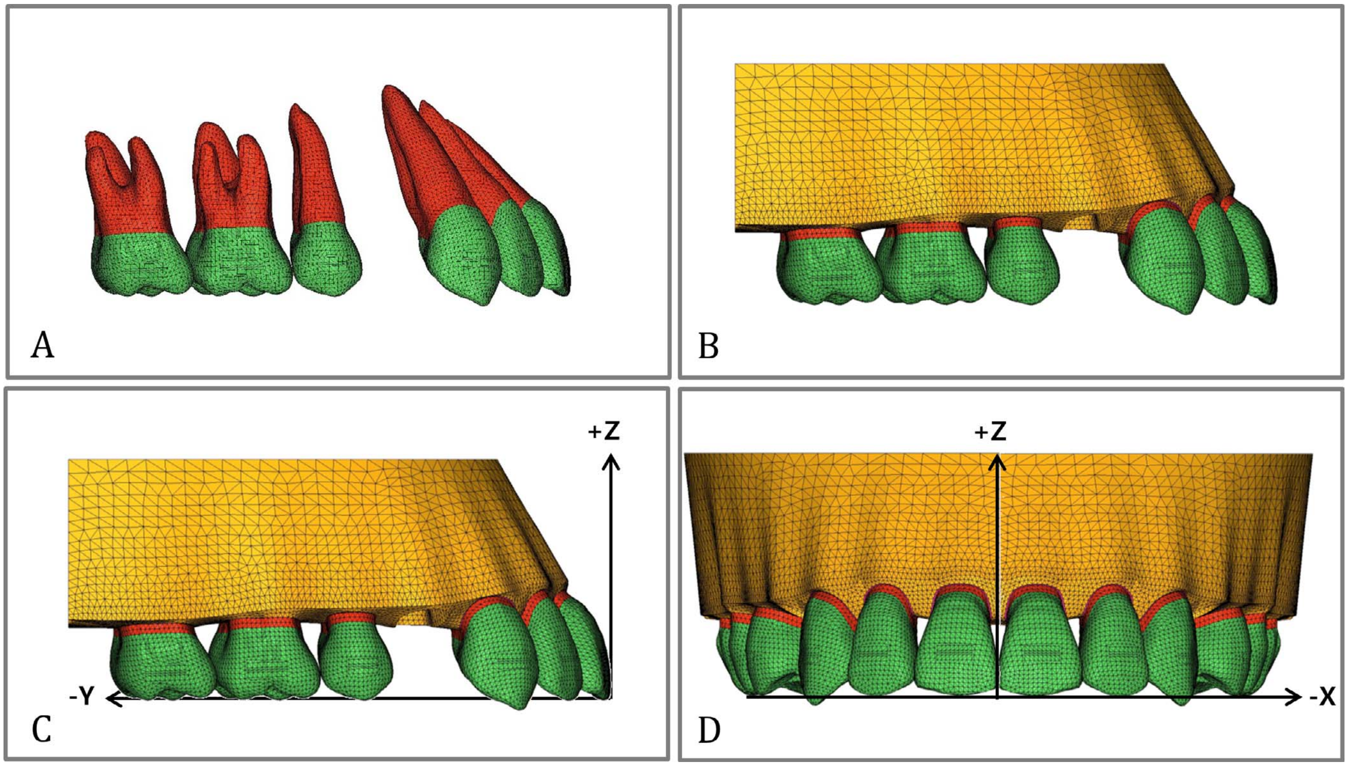

Figure 3. The finite element analysis model. (A) Teeth; (B) lateral views of teeth, PDL, alveolar bone of the maxillary dentition; Schematic representation of the coordinate system; (C) Y-Z plane; and (D) X-Z plane.

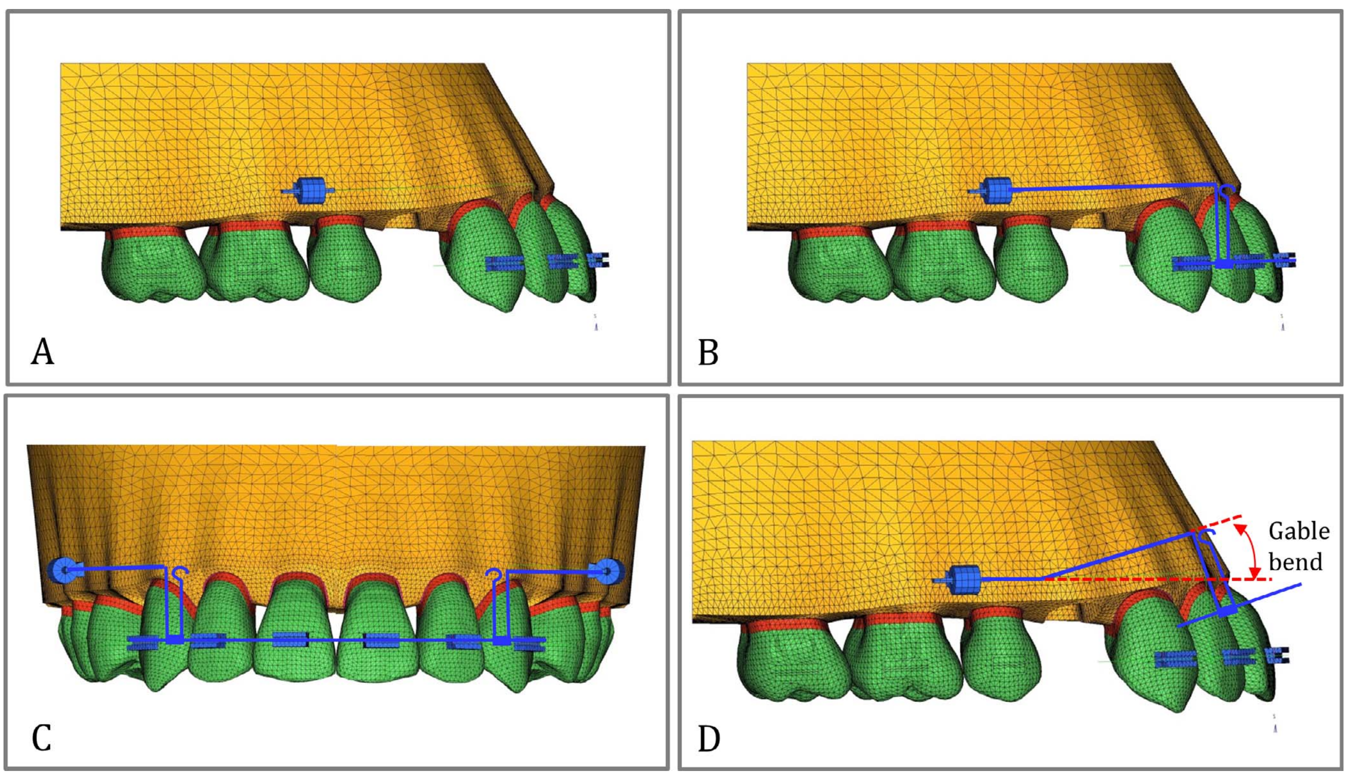

Figure 4. Schematic illustration of CH-retractor with gable bend. (A) C-implant was assumed to be placed between second premolar and first molar, anteroposteriorly; (B,C) CH-retractor was engaged on six anterior teeth, and guiding wire was inserted into the head of C-implant.; (D) Gable bend was applied on posterior extended wire.

Table 2. Comparison of Main Archwire Dimension and Gable Bends on z-Axis Displacement (Retraction Force = 100 g, Hook Length = 7 mm)[a]

Tooth	Archwire Dimension		Gable Bend 0°	15°	30°	45°	60°
Central incisor	0.016 × 0.022-inch NiTi	Root apex	2.41E-02	2.14E-02	2.05E-02	2.02E-02	1.98E-02
		Incisal edge	−8.24E-03	5.58E-03	1.49E-02	2.38E-02	3.27E-02
	0.017 × 0.025-inch NiTi	Root apex	2.43E-02	1.90E-02	1.71E-02	1.58E-02	1.47E-02
		Incisal edge	−7.16E-03	8.39E-03	1.98E-02	3.08E-02	4.18E-02
Lateral incisor	0.016 × 0.022-inch NiTi	Root apex	9.68E-03	6.51E-03	3.76E-02	1.02E-03	−1.72E-03
		Incisal edge	−6.62E-03	2.87E-02	5.70E-02	8.44E-02	1.12E-01
	0.017 × 0.025-inch NiTi	Root apex	9.62E-03	6.50E-03	3.99E-03	1.51E-03	−1.04E-03
		Incisal edge	−4.36E-03	2.59E-02	5.47E-02	8.27E-02	1.11E-01
Canine	0.016 × 0.022-inch NiTi	Root apex	6.94E-03	−5.79E-04	−7.37E-03	−1.44E-02	−2.14E-02
		Cusp tip	−3.23E-02	1.15E-02	6.01E-02	1.09E-01	1.58E-01
	0.017 × 0.025-inch NiTi	Root apex	5.73E-03	8.98E-04	−5.06E-03	−1.13E-02	−1.75E-02
		Cusp tip	−3.09E-02	9.96E-03	5.61E-02	1.03E-01	1.49E-01

[a] NiTi indicates nickel-titanium; Positive figures indicate tooth intrusion, and negative figures indicate extrusion.

guiding archwire (0.017 × 0.025-inch SS) between the lateral incisor and the canine, with a height of 7 mm. The guiding wire extended posteriorly to be placed into the hole of the C-implant (Figure 4B,C). The gable bend was made at the posterior third of the extraction space, activated toward the root (+z), with bends of 0°, 15°, 30°, 45°, and 60° (Figures 2 and 4D). The C-implant, which had a 0.8-mm-diameter hole, was positioned 8 mm above the imaginary bracket position between the second premolar and the first molar (Figure 4A).

The teeth and brackets were connected without interference, each tooth was in contact with the other independently via contact points, and the upper and posterior surface of the maxilla was used as a boundary condition. Although the material properties were isotropic and homogeneous linear elastic bodies, nonlinear analysis was performed because of the geometric nonlinearity in the contact elements between the teeth and between the C-implant head hole and the guiding archwire.

The retraction force was 100 g between ARH and the C-implant head. The tooth displacements were analyzed to trace the midpoints of the incisal edges of the two incisors, the cusp tip of the canine, and each tooth's root apex in the x, y, and z coordinate system. ANSYS 11 (Swanson Analysis System) was used for the finite element analysis on a workstation (XW6400; Hewlett-Packard, Palo Alto, Calif).

RESULTS

The tooth displacement pattern on the z-axis is shown in Table 2 and Figure 5A. With 0° gable bend, all anterior teeth experienced extrusion, and the canines showed a larger amount of extrusion than did the central and lateral incisors. By applying a gable bend above 15°, all anterior teeth exhibited intrusion. The amount of intrusion was proportional to the degree of the gable bends.

The tooth displacement pattern on the y-axis is shown in Table 3 and Figure 5B. For all anterior teeth, an increase in the gable bend decreased the amount of retraction. The difference of the tooth displacement pattern on the y-axis between crown tip and root apex is shown in Table 4. It was calculated by subtracting the incisor edge or cusp tip displacement value from the root apex value in Table 3. In this table, positive figures indicate tooth retroclination, and negative figures indicate proclination. With an increase of the gable bend, the labial crown torque tendency increased in both main archwires. With a 0° gable bend, all data showed lingual crown tipping. With an increase of the gable bend, root retraction increased due to increased labial crown torque. It was assumed that bodily movement of the canine and lateral incisor was accomplished between 0° and 15° gable bend on both main archwires, whereas bodily movement of the central incisor was assumed for a gable bend between 30° and 45° on the 0.016 × 0.022-inch NiTi and between 15° and 30° on the 0.017 × 0.025-inch NiTi.

DISCUSSION

Torque and vertical control of the anterior segment are important during premolar space closure. Torque loss of the anterior teeth with an extrusive tendency can easily occur with sectional retraction. The CH-retractor was developed, which combines the anterior NiTi sectional and posterior SS archwires, using gable bends for effective control of the anterior teeth.[8]

Without a gable bend, a retraction force (F_H) generates a clockwise moment (M_{FH}), because the force vector passes below the center of resistance (CR) of the six anterior teeth (Figure 6A). This moment leads to anterior torque loss (see 0° gable bend on Table 4) and an extrusion tendency of anterior teeth

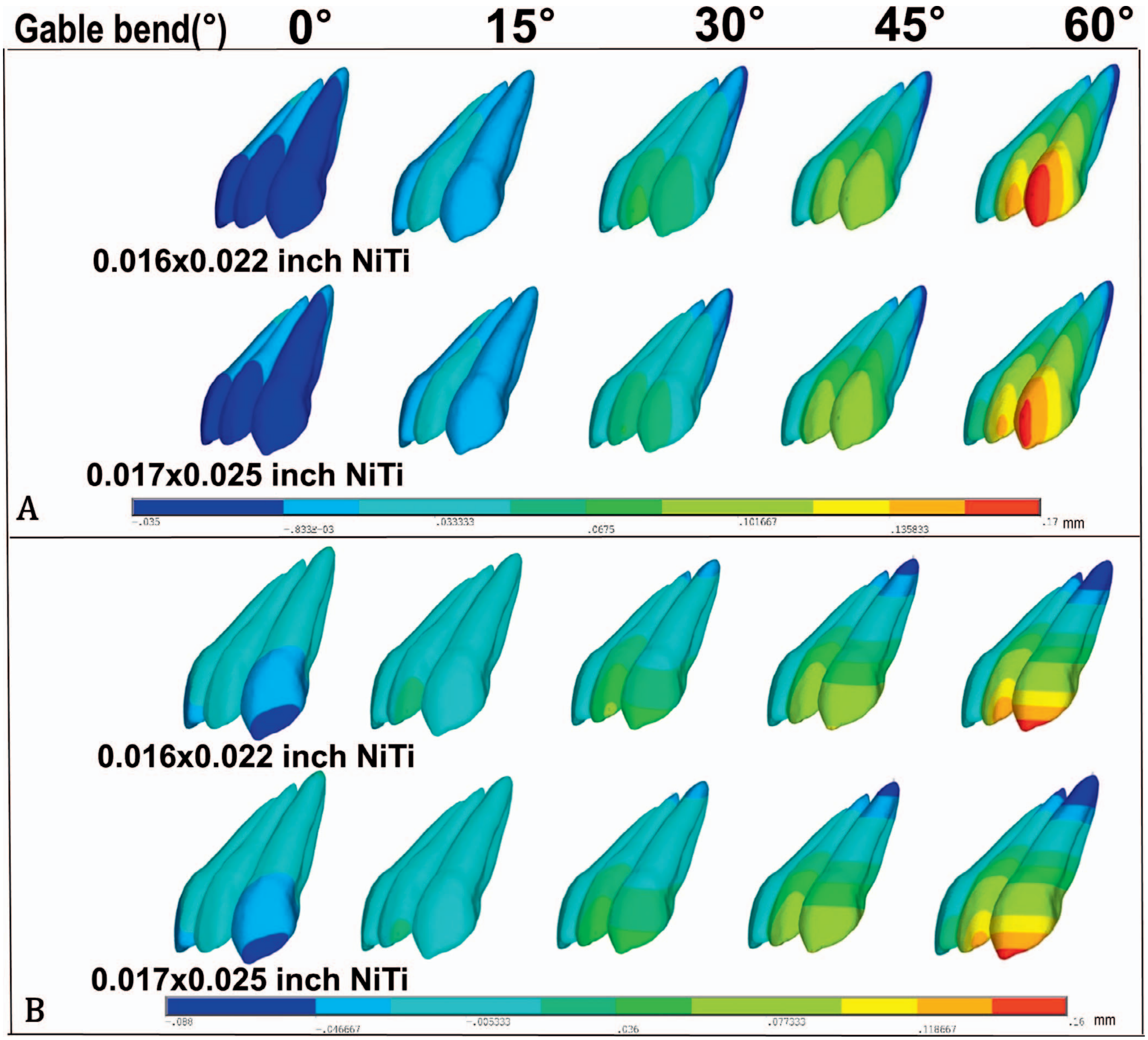

Figure 5. Comparison of main archwire dimension and gable bends (retraction force = 100 g, hook length = 7 mm). (A) Z-axis displacement (Z-axis: [+] = intrusion, [–] = extrusion). (B) Y-axis displacement (Y-axis: [+] = proclination, [–] = retraction).

(see 0° gable bend on Table 2). This is not desirable in most cases. The gable bend is an essential factor of the CH-retractor system, designed to offset these tendencies (Figure 6B). A gable bend in the SS archwire segments generates a vertical force (F_V). Because an anterior retraction hook is located between the lateral incisor and canine, the vertical force vector passes in front of the anterior segment CR. The result is that this vertical force generates a counterclockwise moment (M_{FV}) that will control the anterior teeth during en masse retraction. An increase in the gable bend increases the vertical force and the counterclockwise moment.

The gable bend generates vertical force (F_N) as a reactive force at the C-implant head area as a result of Newton's law of motion (Figure 6B). This force induces friction between the C-implant head and the SS archwire. Because tooth movement is determined by the sum of all forces applied to the teeth, friction can considerably alter the force system. The classic formula below defines the relationship between friction force (F_F), coefficient of friction (μ), and forces operating at 90° to the archwire (ie, normal forces [F_N]): $F_F = \mu \times F_N$.

As the vertical force increases by increasing the gable bend, the F_N also increases, and friction

Table 3. Comparison of Main Archwire Dimension and Gable Bends on y-Axis Displacement (Retraction Force = 100 g, Hook Length = 7 mm)[a]

			Gable Bend (y-Axis)				
Tooth	Archwire Dimension		0°	15°	30°	45°	60°
Central incisor	0.016 × 0.022-inch NiTi	Root apex	−1.63E-03	−8.33E-03	−1.35E-02	−1.86E-02	−2.36E-02
		Incisal edge	−4.08E-02	−2.71E-02	−1.95E-02	−1.28E-02	−6.05E-03
	0.017 × 0.025-inch NiTi	Root apex	−2.38E-03	−1.02E-02	−1.64E-02	−2.25E-02	−2.87E-03
		Incisal edge	−4.04E-02	−2.20E-02	−1.14E-02	−1.97E-03	7.32E-03
Lateral incisor	0.016 × 0.022-inch NiTi	Root apex	−2.55E-03	−2.18E-02	−3.65E-02	−5.09E-02	−6.53E-02
		Incisal edge	−2.17E-02	1.26E-02	4.12E-02	6.94E-02	9.77E-02
	0.017 × 0.025-inch NiTi	Root apex	−3.93E-03	−2.04E-02	−3.56E-02	−5.04E-02	−6.51E-02
		Incisal edge	−1.94E-02	1.05E-02	3.92E-02	6.75E-02	9.58E-02
Canine	0.016 × 0.022-inch NiTi	Root apex	1.90E-02	−4.29E-03	−3.18E-02	−5.94E-02	−8.71E-02
		Cusp tip	−5.14E-02	−3.79E-03	4.91E-02	1.02E-01	1.56E-01
	0.017 × 0.025-inch NiTi	Root apex	1.98E-02	−5.70E-03	−3.24E-02	−5.93E-02	−8.62E-02
		Cusp tip	−5.05E-02	−2.92E-03	4.83E-02	1.00E-01	1.52E-01

[a] NiTi indicates nickel-titanium; Positive figures indicate anterior, and negative figures indicate posterior.

consequently increases. Friction will cause some decrease in the horizontal retraction force and the clockwise moment generated by the retraction force. In summary, as the gable bend increases, it increases the counterclockwise moment and decreases the clockwise moment generated by the total horizontal force, which reinforces the labial tipping moment and, consequently, the root retraction, of the anterior teeth (Table 4).

In this study, a gable bend increase caused more labial crown torque. With a 0° gable bend, all data showed lingual crown tipping. With an increase in the gable bend, the labial crown torque increased. It is possible, therefore, to control the retraction inclination of the anterior teeth with changes of the gable bend. When the gable bend was increased in the incisors, the retraction of the root was increased and the retraction amount of the crown was decreased. Therefore, by adjusting the degree of the gable bend, the displacement pattern of the incisors during retraction could be controlled.

Because the anterior archwire is composed of NiTi, initial alignment of the incisors is possible even during retraction. Apparent bodily movement of the canine and lateral incisor was observed using a 0°∼15° gable bend on both posterior archwires and bodily movement of the central incisor between 30° and 45° of gable bend on the posterior archwires with 0.016 × 0.022-inch NiTi and between 15° and 30° of gable bend on the posterior archwires with 0.017 × 0.025-inch NiTi without deformation. These data can be used as reference data for CH-retractor clinical application. However, every patient presents with different conditions, such as varying alveolar bone levels, bone densities, CR positions, and so on.[19] Therefore, these standardized data can act as a guide in clinical situations.

CONCLUSIONS

The hypothesis was verified in this FEM study. Three-dimensional en masse controlled retraction of the six anterior teeth can be accomplished using the CH-retractor with gable bends without the need for posterior appliances. Based on the findings of this study, the following can be concluded:

- The amount of intrusion of the anterior teeth increases with an increase in the gable bends.
- With an increase in the gable bends, crown labial torque tendency increased in both main archwires.
- It is assumed that bodily movement of the canine and lateral incisor was accomplished with a 0°∼15° gable bend on both posterior archwire segments, whereas bodily movement of the central incisor required a

Table 4. Displacement Pattern of Individual Anterior Teeth on y-Axis[ab]

		Gable Bend				
Tooth	Archwire Dimension	0°	15°	30°	45°	60°
Central incisor	0.016 × 0.022-inch NiTi	3.92E-02	1.88E-02	6.00E-03	−5.80E-03	−1.76E-02
	0.017 × 0.025-inch NiTi	3.80E-02	1.18E-02	−5.00E-03	−2.05E-02	−1.02E-02
Lateral incisor	0.016 × 0.022-inch NiTi	1.92E-02	−3.44E-02	−7.77E-02	−1.20E-01	−1.63E-01
	0.017 × 0.025-inch NiTi	1.55E-02	−3.09E-02	−7.48E-02	−1.18E-01	−1.61E-01
Canine	0.016 × 0.022-inch NiTi	7.04E-02	−5.00E-04	–	−1.61E-01	−2.43E-01
	0.017 × 0.025-inch NiTi	7.03E-02	−2.78E-03	−8.07E-02	−1.59E-01	−2.38E-01

[a] NiTi indicates nickel-titanium; Zero indicates translation; positive figures indicate tooth reclination, and negative figures indicate proclination.
[b] It is calculated by subtracting incisor edge or cusp tip displacement value from root apex value on Table 3.

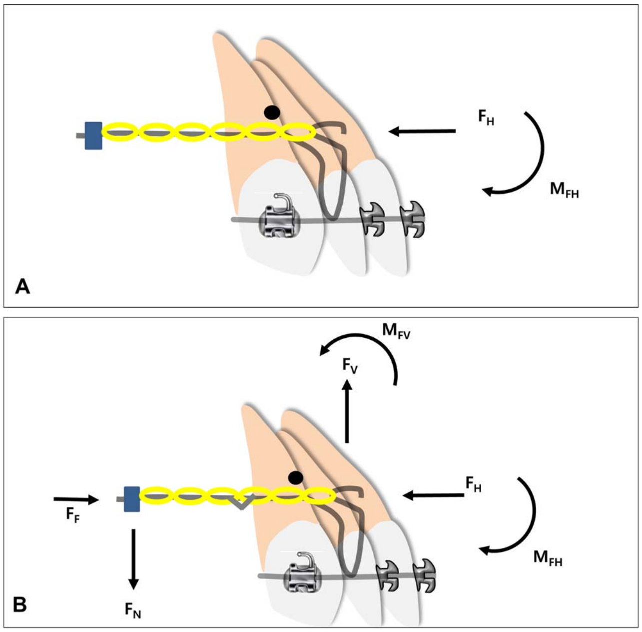

Figure 6. Biomechanical illustration of CH-retractor system without gable bend (A) and with gable bend (B). Black dot: center of resistance. F_V indicates vertical force generated by gable bend; F_H, horizontal force generated by orthodontic elastics; F_N, normal force generated as a reactive force of F_V; F_F, friction force between C-implant head and SS archwire; M_{FV}, moment generated by vertical force; abd M_{FH}, moment generated by retraction force.

30°∼45° gable bend when using anterior segments of 0.016 × 0.022-inch NiTi and 15°∼30° gable bend with 0.017 × 0.025-inch NiTi.

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