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Initial effect of multiloop edgewise archwire on the mandibular dentition in Class III malocclusion subjects. A three-dimensional finite element study

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SUMMARY The purpose of this study was to compare the effect of a multiloop edgewise archwire (MEAW) with a plain ideal archwire (IA) on distal *en masse* movement of the mandibular dentition. A three-dimensional finite element model (3D FEM) of the mandibular dentition, without third permanent molars, was constructed to include the periodontal membrane (PDM), alveolar bone, standard edgewise bracket (0.018 × 0.025 inch), stainless steel IA (0.016 × 0.022 inch), and MEAW (0.016 × 0.022 inch). Stress distribution and displacement of the mandibular dentition were analyzed when Class III intermaxillary elastics (300 g/side) and 5 degree tip-back bends from the first premolar to the second molar were applied to the IA and the MEAW for distal *en masse* movement of the mandibular dentition.

Compared with the IA, the discrepancy in the amount of tooth displacement was less and individual tooth movement with the MEAW was more uniform and balanced. There was minimal vertical displacement or rotation of the teeth with the MEAW when compared with the IA. The MEAW seems to have advantages for distal *en masse* movement of the mandibular dentition.

Introduction

The incidence of a Class III malocclusion is predominant in Korean orthodontic patients (48%; Yang, 1995) and mandibular prognathism is one of the most prevalent complaints (Im *et al.*, 2003). If the skeletal pattern of a Class III malocclusion is within the range of orthodontic treatment, fixed orthodontic appliances with a dentoalveolar compensation mechanism can achieve a normal occlusion (Ishikawa *et al.*, 2000; Costa Pinho *et al.*, 2004; Janson *et al.*, 2005).

There are numerous studies concerning the characteristics of dentoalveolar compensation according to the skeletal pattern (Downs, 1948; Schudy, 1964; Sassouni, 1969; Bibby, 1980; Casko and Sheperd, 1984; Choi and Yang, 1984; Chang and Moon, 1999; Kim *et al.*, 2005). Jacobson (1975) suggested that a Class III molar relationship could be changed into a Class I relationship as the occlusal plane would rotate upward and forward with Class III elastics. To correct an anterior crossbite and Class III molar relationship, distal *en masse* movement of the mandibular dentition is usually required (Figure 1).

The multiloop edgewise archwire (MEAW, 0.016 × 0.022 inch, Permachrome standard, 3M Unitek, Monrovia, California, USA) could be considered an effective tool for distal *en masse* movements (Kim, 1987; Baek and Yang, 1991; Chun and Nahm, 1991; Sato, 1992; Yang *et al.*, 2001; Chang *et al.*, 2004). In the finishing stages, engagement of full-size rectangular stainless steel wires of high stiffness into fully programmed brackets minimizes individual tooth movement. However, multiple L-loops and tip-back bends incorporated in the MEAW together with intermaxillary elastics can allow individual tooth movements and make it possible to upright posterior teeth, to change the inclination of the occlusal planes, to correct the occlusal sagittal relationship, and to obtain the correct intercuspation in a significantly shorter time (Sato, 1992; Chang *et al.*, 2004). Jin *et al.* (2004) reported that the main change after treatment with the MEAW technique was dentoalveolar compensation.

Although there are several studies concerning distal *en masse* movement of the maxillary dentition (Chun and Nahm, 1991; Lee and Nahm, 1994; Chang *et al.*, 2004), research is still required. The purpose of this study was to investigate the effect of MEAW on initial stress distribution and displacement for distal *en masse* movement of the mandibular dentition using a three-dimensional finite element model (3D FEM).

Materials and methods

A 3D FEM was used to construct the anatomical structures and physical characteristics of the mandibular teeth, the periodontal membrane (PDM), and the alveolar bones, with restraints 3 mm below the apices of the mandibular dentition (Figure 2). The reason for the restraints was to permit movement of the teeth in the alveolar bone rather than the basal bone. Fabrication of the 3D FEMs for each tooth, PDM, alveolar bone, standard edgewise brackets (0.018 × 0.025 inch, 3M Unitek) and plain continuous ideal archwire (IA, 0.016 × 0.022 inch, 3M Unitek), and MEAW (0.016 × 0.022 inch) were followed using the protocol of Chang *et al.* (2004).

Briefly, 3D FEMs of the teeth were constructed according to Wheeler (1965), Choi and Yang (1984), and Kim *et al.* (1992). The maxillary and mandibular dentitions were aligned according to the Tru-arch form (medium size, Ormco Co., West Collins Orange, California, USA). The 3D FEMs of the PDM were constructed to fit outside of the root with a thickness of 0.25 mm (Coolidge, 1937) and those for the alveolar bone of the mandible to fit the PDM (Singh *et al.*, 1998, 2000). 3D FEMs of 0.018 × 0.025-inch standard edgewise brackets (3M Unitek) were made and attached to the facial axis (FA) point of the clinical crown so that the centre of the bracket slot coincided with it (Andrews, 1972). The 3D FEMs of posted IA and MEAW were designed according to Tru-arch form (medium size, Ormco Co.). The posts in the IA were positioned between the brackets of the mandibular lateral incisor and canine for Class III elastics. After including 5 degree tip-back bends from the first premolar to the second molar, Class III elastics were applied to the posts of the IA and the first L-loop of the MEAW between the mandibular lateral incisor and canine. The amounts of torque in the IA and MEAW were adjusted to be passive in the bracket slot, as the aim of this study was to investigate only distal *en masse* movement of the mandibular dentition.

Although the PDM is known to be a non-linear visco-elastic material, the mechanical properties of 3D FEMs were considered to have linear elasticity and isometric properties of the same quality. Young's modulus (Kgf/mm^2) and Poisson's ratio for the tooth (2.0×10^3, 0.3), PDM (6.8×10^{-2}, 0.49), alveolar bone (1.4×10^3, 0.3), and bracket and wire (21.4×10^3, 0.3) were allocated according to Tanne *et al.* (1987) and Chang *et al.* (2004). The 3D FEMs for the teeth and standard edgewise brackets were made with 3D quadrangular and hexagonal elements, the PDM with thin shell elements, and the IA and MEAW with 3D beam elements. The number of 3D elements was 9585, and the nodes of the IA and MEAW, 2175 and 2750, respectively.

Using an imaginary line that passed through the FA point of the crown parallel to the occlusal plane, displacements could be measured at each point. The co-ordinate system consisted of X, Y, and Z axes perpendicular to one another. The X axis represented the mesiodistal direction, the Y axis the labiolingual or buccolingual direction, and the Z axis the vertical direction (Figure 3). It was possible to evaluate tipping, bodily displacements, vertical displacements, and rotations in three dimensions.

When a Class III elastic force (300 g/side) was applied into the IA and MEAW with 5 degree tip-back bends, initial displacement was simulated and measured in the 3D FEM. The computer system used in this study was an Indigo O2 (R5500 Silicon Graphics, Mountain View, California, USA) and the 3D FEM program, ANSYS (version 5.3, Swanson Analysis System Inc., Canonsburg, Pennsylvania, USA).

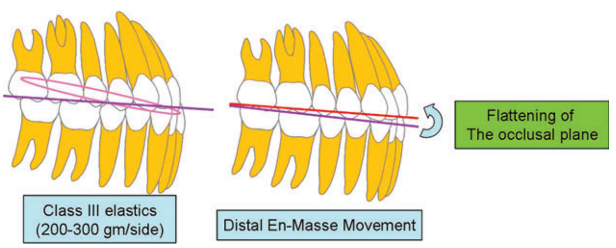

Figure 1 Biomechanics of the fixed orthodontic appliance treatment for Class III malocclusions.

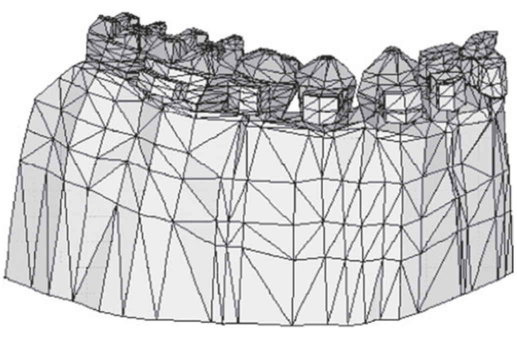

Figure 2 Oblique view of the three-dimensional finite element model of the lower right dentition. The model consists of the teeth, periodontal membrane, alveolar bone, and brackets.

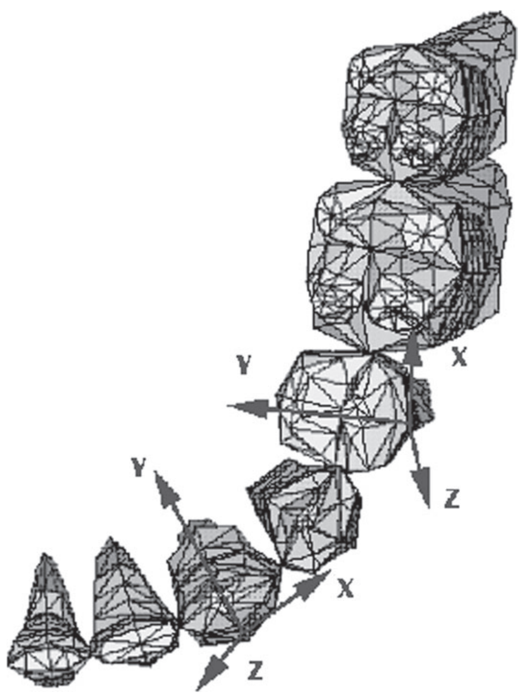

Figure 3 The reference co-ordinate system. X axis, mesiodistal direction; Y axis, labiolingual direction; Z axis, vertical direction.

Results

The IA showed that stress was concentrated on specific distal areas such as the mandibular canine and first premolar adjacent to the posts, where Class III elastics were applied (Figure 4A). However, MEAW revealed relatively even distribution of stress throughout the whole dentition in spite of Class III elastics (Figure 4B).

The initial lingual and distal bodily displacements and lingual tipping movements were concentrated on the anterior part of the mandibular dentition (Figure 5A–C). However, the amounts of these bodily displacements and tipping movements with MEAW were lower and more uniform than with the IA.

For mesiodistal tipping movements, IA showed that distal tipping movements occurred at the anterior teeth and mesial tipping movements at the mandibular premolars and first molar (Figure 5D). Although mesiodistal tipping movements with the MEAW demonstrated the same tendency as with the IA, the values were lower and individual tooth movement was more uniform with the MEAW than the IA (Figure 5D).

For vertical displacements with the IA, extrusions occurred at the mandibular central incisor, premolars, and first molar, with slight intrusion at the lateral incisor and canine (Figure 5E). The discrepancy in the amount of extrusion and intrusion was higher with the IA than with the MEAW. However, there was no significant vertical displacement of the whole mandibular dentition with the MEAW (Figure 5E).

For the MEAW, distolingual rotations of the lateral incisor and canine were prominent due to flexibility of the archwire between first L-loop and the adjacent teeth. In contrast, rotation of posterior teeth was not observed with the MEAW (Figure 5F).

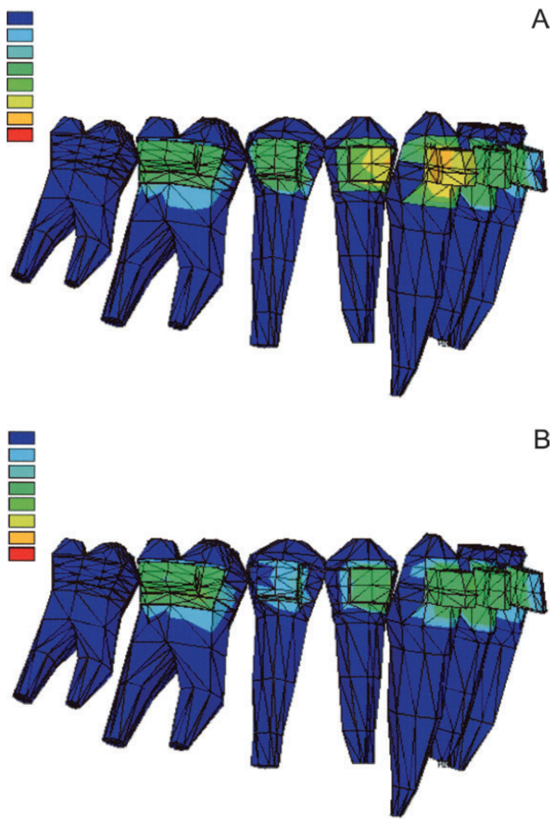

Figure 4 Comparison of initial stress distribution of the mandibular dentition between a continuous plain ideal archwire (A) and multiloop edgewise archwire (B).

Discussion

Class III malocclusions can be corrected with a combination of clockwise rotation of the mandible, counterclockwise rotation of the occlusal plane, and dentoalveolar compensation with distal *en masse* movement of the lower dentition (Baek, 2006) (Figure 6). Chang *et al.* (2004) reported that the MEAW had the advantages of less discrepancy in the amount of tooth displacement and relatively more even distribution of stress throughout the whole dentition than an IA. This means that distal *en masse* movement of the entire mandibular dentition could be more easily carried out with the MEAW. The reason for these phenomena is due to the relatively lower load-deflection ratio in the posterior segments of the MEAW, which originates from the longer horizontal length of the L-loops (Yang *et al.*, 2001).

In addition, Jin *et al.* (2004) reported that the main change after treatment of Class III malocclusions using the MEAW technique was dentoalveolar compensation. They also found that improvement in molar relationship and overjet was achieved with upright and distal movement of the lower posterior teeth. Therefore, it can be considered that MEAW is more efficient for distal *en masse* movement than the IA.

If the IA cannot efficiently upright the lower molars distally, the lower incisors have to be extruded and excessively lingually tipped to rotate the mandibular occlusal plane counterclockwise. This could negatively affect the stability of the treatment result. However, the MEAW can effectively upright the lower molars distally and minimize extrusion of the lower incisors (Figure 5). Therefore, correction of a Class III malocclusion will be relatively easier with the MEAW than with the IA.

Long-term use of Class III elastics can result in extrusion of the upper molars and labioversion of the upper incisors. In patients with Class III malocclusions with hyperdivergent facial patterns and labioversed upper incisors, it is not desirable to use Class III elastics from the upper molar to the lower anteriors. With the recent development of miniscrews, Class III elastics from a miniscrew, inserted in the posterior buccal gingival area of the upper arch, to a MEAW in the lower arch can prevent these side-effects (Baek, 2006).

In order to evaluate the true relationship between tooth movement and orthodontic force, it is necessary to quantify not only the force system applied to the teeth but also the

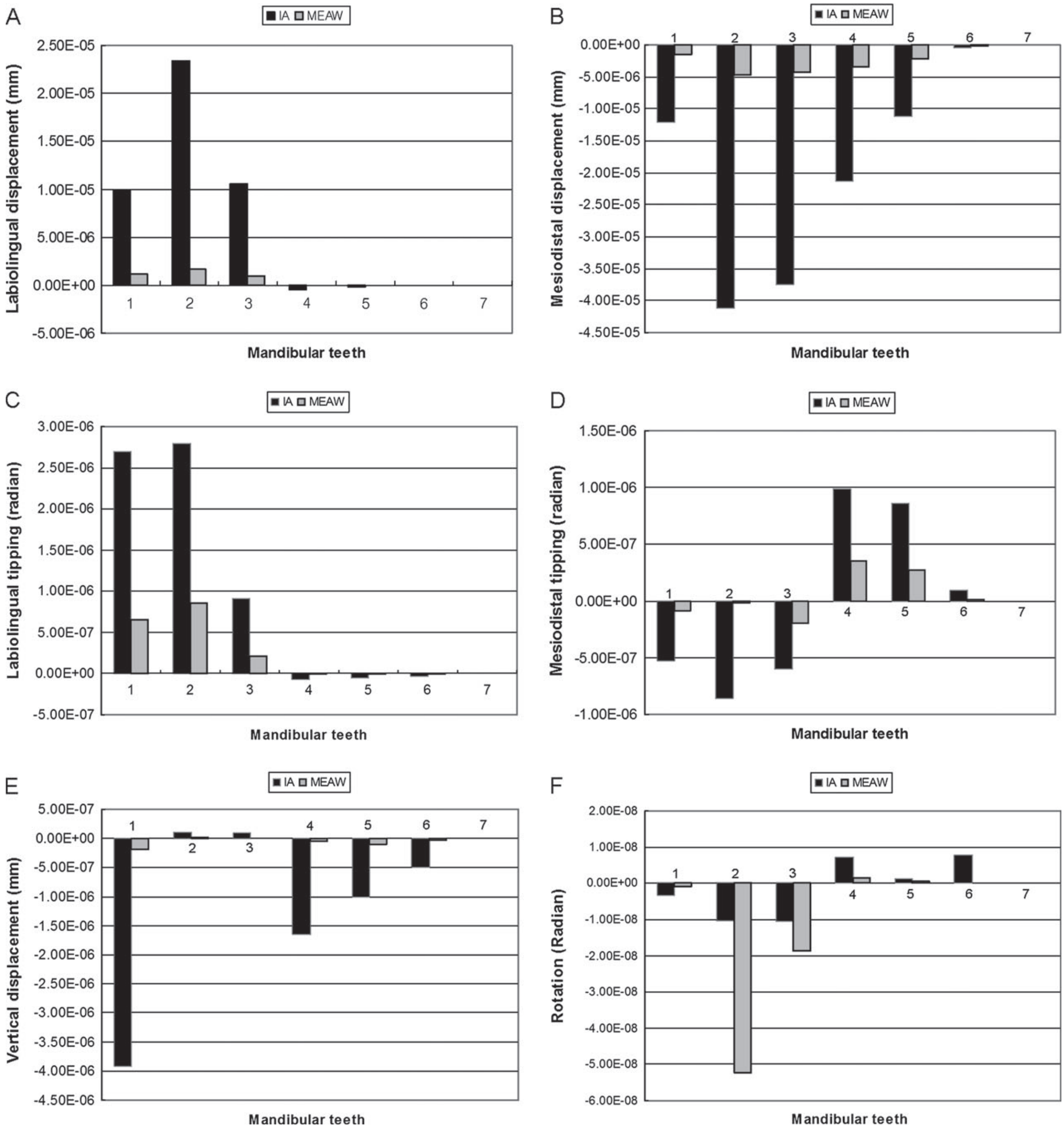

Figure 5 Comparison of displacement, tipping, and rotation between the ideal archwire (IA) and the multiloop edgewise archwire (MEAW) with 5 degree tip-back bends and Class III elastics. (A) Labiolingual bodily displacement; +, lingual displacement; –, labial displacement. (B) Mesiodistal bodily displacement; +, mesial displacement; –, distal displacement. (C) Labiolingual tipping; +, crown lingual tipping; –, crown labial tipping. (D) Mesiodistal tipping; +, crown mesial tipping; –, crown distal tipping. (E) Vertical displacement; +, intrusive translation; –, extrusive translation. (F) Rotation; +, mesiolingual rotation; –, distolingual rotation. 1, right central incisor; 2, right lateral incisor; 3, right canine; 4, right first premolar; 5, right second premolar; 6, right first molar; 7, right second molar.

periodontal stress and strain generated by the orthodontic forces. Since periodontal stress is transferred to the alveolar bone and induces bone remodelling and tooth movement, the amount of stress and strain in the PDM have been calculated to quantify simulated orthodontic tooth movement using computer-based programs (Williams and Edmundson, 1984; Tanne *et al.*, 1987; Fotos *et al.*, 1990; Andersen *et al.*, 1991; Chun and Nahm, 1991; McGuinness *et al.*, 1992; Cobo *et al.*, 1993, 1996; Hwang and Suhr, 1994; Puente *et al.*, 1996; Chang *et al.*, 2004). However, these studies have some limitations because only the initial movements that occur in the PDM were calculated with the mathematical model. This initial movement should be differentiated from secondary movements that are mediated by continuous bone resorption

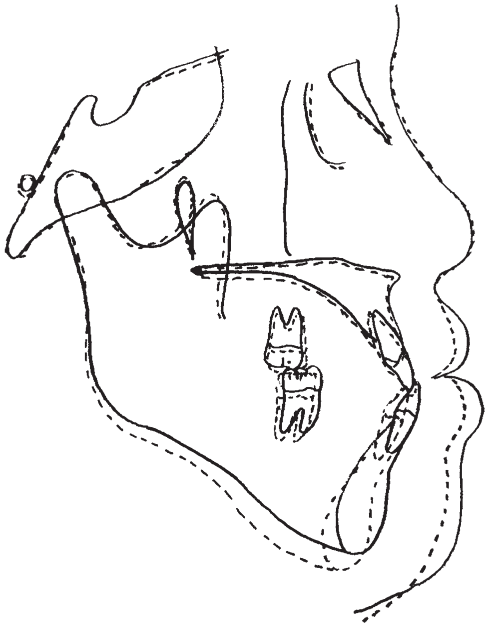

Figure 6 Mechanism for correction of Class III malocclusions. Clockwise rotation of the mandible, counterclockwise rotation of the occlusal plane, and dentoalveolar compensation such as labioversion of the upper incisors and linguoversion of the lower incisors with distal *en masse* movement. Pre-treatment, dashed line; post-treatment, dotted line.

in pressure and deposition at the tension sides. Since these movements cannot be separated (Tanne *et al.*, 1987), it is necessary to develop a time-dependent 3D FEM analysis. The other limitation is that the results were based on the fact that the thickness of the PDM was uniformly 0.25 mm and linear elastic, isotropic, and the continuous properties (Coolidge, 1937; Cattaneo *et al.*, 2005). However, it has an hourglass shape so that the centre is narrowest (Kronfeld, 1931) and the thickness is variable at 0.25 mm ± 50 per cent. According to Cattaneo *et al.* (2005), the tensile stresses calculated in the PDM and the initial displacements of the teeth will be grossly underestimated by approximately 50 per cent. These differences might result in an underestimation of tooth movement (Cattaneo *et al.*, 2005). After orthodontic force is applied, histological changes can alter the physical properties of the tissues and therefore Young's modulus and Poisson's ratio (McGuinness *et al.*, 1992). For these reasons, the secondary response could be different from the initial response of the PDM. Also, the errors associated with the bony tissues, deformation of bracket, forces of circum-oral muscles, and bite forces were not considered in this study. To overcome these limitations, it is necessary to develop a more accurate modelling technique and a time-dependent 3D FEM analysis.

Conclusion

The discrepancies in the amounts of bodily displacement and tipping were lower and the individual tooth movement was more uniform and balanced with the MEAW than with the IA. The MEAW produced less extrusive vertical displacement and rotation of each tooth compared with the IA. Therefore, the MEAW might be a more suitable tool for distal *en masse* movement of the mandibular dentition for correction of Class III malocclusions.

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