

An experimental study on mandibular expansion: increases in arch width and perimeter

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SUMMARY The purpose of this study was to estimate the increase in arch perimeter associated with mandibular lateral expansion. The mandibular expansion was simulated using a three-dimensional (3D) finite element method (FEM) and a computer graphics technique (3D simulation). The centre of rotation of molars during movement accompanied by lateral expansion was calculated using 3D FEM. The geometry of the model was determined using the mandibular bone of an East Indian skeletal specimen and 1 mm computer tomogram (CT) slices. The 3D set-up simulation was then conducted using 3D computer graphics instead of performing a manual set-up. Rotational movement was induced in the buccal segment, from the first premolar to second molar, in the 3D set-up model around the location of the centre of rotation (4.5 mm below the root apex of the first molar) derived from the FEM.

According to 3D simulation, the model showed an opening space of 1.43 mm between the canine and first premolar, and thus a change in arch perimeter of 2.86 mm. The tip of the mesio-lingual cusp of the first molar moved 3.88 mm laterally, resulting in a change in inter-molar width of 7.76 mm. These values mean that a 1 mm increase in arch width resulted in an increase in arch perimeter of 0.37 mm. This result would be of value clinically for prediction of the effects of mandibular expansion.

Introduction

Rapid maxillary expansion (RME) is a commonly used treatment technique that has become increasingly popular during the last 25 years (Chang *et al.*, 1997). In contrast, mandibular expansion has not until recently been recommended (Sandstrom *et al.*, 1988). The reason for this is that whilst the maxilla has a mid-palatal suture, the mandible does not. While RME increases the transverse dimension of the maxillary arch by separation of the suture (Haas, 1961; Bishara, 1987), the effects of mandibular expansion localized alveolar bone and may induce tooth inclination (Haas, 1961, 1965). Therefore, as a general rule, mandibular expansion is not thought to be stable after retention. However, Walter (1962) concluded that the mandibular arch width could be expanded permanently. If stability after mandibular expansion

is related to tooth inclination, it is important to investigate the changes of tooth inclination during expansion. Furthermore, it is clinically useful to estimate the increase in arch perimeter associated with expansion. In this study, mandibular expansion was simulated using a three-dimensional (3D) model in order to assess the changes in tooth inclination and then to calculate the increase in arch perimeter.

Materials and methods

Calculation of the centre of rotation using the finite element method

Before considering expansion for the entire dental arch, the centre of rotation of molars during movement accompanied with lateral expansion must be known. Figure 1 shows a finite element model (FEM) of a second premolar and

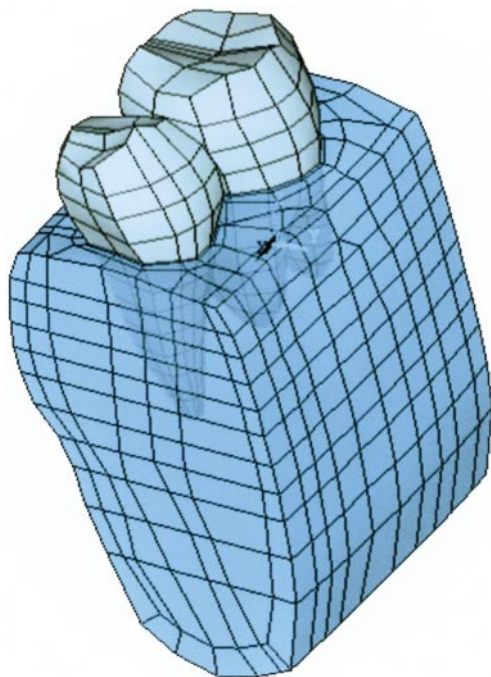


Figure 1 Finite element model (FEM) of a second premolar and first molar constructed to calculate the centre of rotation.

first molar constructed to calculate the centre of rotation. The geometry of the FEM was determined using the mandibular bone of an East Indian skeletal specimen housed at the Department of Anatomy, Nihon University School of Dentistry, and 1 mm computer tomogram (CT) slices were digitized with a microcomputer (CPU: Intel Pentium III 600 MHz, RAM: 128 MB, Hard Disk: 12 GB) and a specially written 3D CAD program (computer language: Microsoft Corp. VB6). From these images, the FEM was constructed (Figure 1). The material properties of the elements in this model were defined using data from a previous study (Middleton *et al.*, 1996; Table 1). The model consisted of a total of 2126 nodal points and 1599 3D elements.

The ANSYS rev. 5.0 program (Cybernet System Co., Tokyo, Japan) was used to calculate the strains and displacements at each nodal point. Expansion forces of 0.5×10^{-3} N and 20×10^{-3} N were used for the premolar and molar, respectively, to be parallel to the occlusal

Table 1 Material properties defined in the finite element model (FEM).

Material	Young's modulus (N/mm ²)	Poisson's ratio
Tooth	84,100	0.2
Cortical bone	13,800	0.26
Cancellous bone	345	0.3
Periodontal ligament	0.75	0.45

plane supposing a pure horizontal force (Figure 2). The convergence point of the perpendicular lines to the displacement vector at nodal points of the first molar was calculated as the centre of rotation.

Simulation of expansion for entire dental arch

The 3D set-up simulation was conducted by using 3D computer graphics instead of performing a manual set-up using a lower plaster model. Figure 3 shows the 3D set-up model constructed

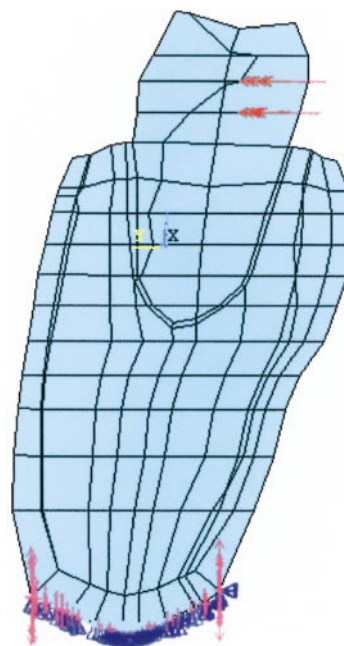


Figure 2 Boundary conditions. Expansion forces were applied to be parallel to the occlusal plane (red arrows). Nodes consisting of the inferior border of the mandible were restricted to 3 degrees of freedom (blue marks).

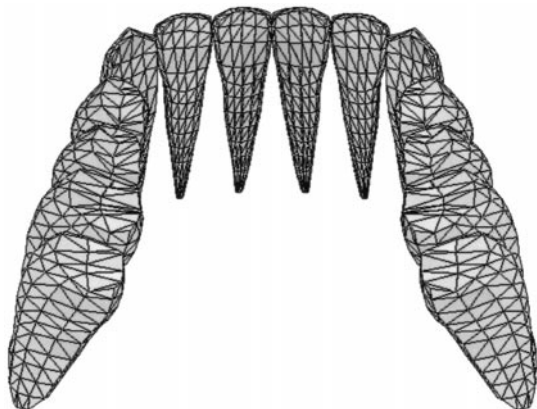


Figure 3 3D set-up simulation model constructed using the 3D CAD program, assuming a constricted dental arch.

in the microcomputer, assuming a case of constriction. This model was made with the 3D CAD program, the same software as used in the FEM. Each tooth size was determined from reference values described by Wheeler (1969).

Following the simulation set-up, rotational movement was induced in the buccal segment, from the first premolar to the second molar, in the 3D set-up model around the location of the centre of rotation derived from the FEM. The 3D simulation regarded canine to canine in the 3D set-up model as an immovable segment (Figure 3). Lateral expansion was produced by uprighting the buccal segment 10 degrees laterally around the centre of rotation.

In this study, an opening of a space between the canine and first premolar was regarded as an increase in dental arch perimeter. Relationships among the increases in arch width, perimeter, and changes in tooth axis were also considered.

Results

The displacements at the first molar level obtained from the FEM are shown in Figure 4. The centre of rotation was located 4.5 mm below the root apex of the first molar (Figure 5).

3D set-up simulation was then performed at the level of the centre of rotation. After lateral expansion of the lower buccal segment, the model showed a space of 1.43 mm between the canine and first premolar, and thus a change in



Figure 4 Results of displacements at the first molar derived from 3D FEM. The dashed line is FEM before expansion and the blue line after expansion.

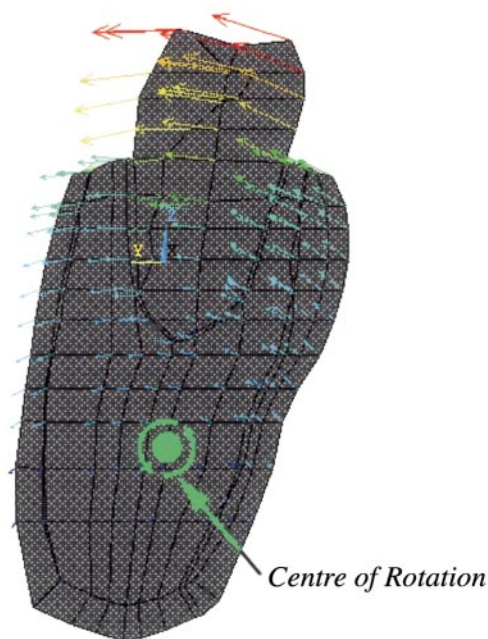


Figure 5 The centre of rotation was determined as the convergence point of perpendicular lines to the displacement vectors at nodal points making up the first molar.

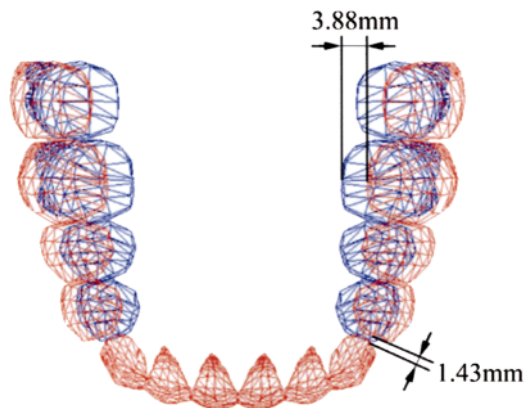


Figure 6 Increases in arch width and perimeter due to expansion involve labial inclination of the first molar by 10 degrees. After lateral expansion of the lower buccal segment, the model showed an opening space of 1.43 mm between canine and first premolar, and a change in arch perimeter of 2.86 mm. The tip of the mesio-lingual cusp of the first molar moved 3.88 mm laterally, resulting in a change in inter-molar width of 7.76 mm.

arch perimeter of 2.86 mm. The tip of the mesio-lingual cusp of the first molar moved 3.88 mm laterally, resulting in a change in inter-molar width of 7.76 mm (Figure 6). These values mean that 1 mm of inter-molar expansion increases the perimeter by 0.37 mm.

Discussion

Angle (1887, 1907) opposed the use of extractions, and much controversy has surrounded this topic (Dewel, 1964, 1981). In recent years, this debate has rekindled with the advance of expansion techniques.

RME has been applied not only in infants, but also in adults (Handelman *et al.*, 2000). For adult patients, the maxilla can be widened by means of RME, increasing the transpalatal width and eliminating or reducing the dark spaces in the 'buccal corridors' (McNamara, 2000). That author also stated that RME, for aesthetic purposes, will become increasingly used to treat patients with narrow dental arches. Furthermore, following RME, not only is there expansion of the maxillary, but also the mandibular dental arch. The position of the lower dentition may be influenced by the maxillary skeletal morphology.

Lower arch widening is due primarily to 'decompensation' and an uprighing of the lower posterior teeth, which often erupt into occlusion in a more lingual orientation because of the associated constricted maxilla (McNamara, 2000).

From the above-mentioned reports and also that of Walter (1962), who stated that mandibular arch width could be expanded permanently, mandibular expansion has been positively applied clinically (Hamula, 1993).

Few attempts have been made to quantify the changes in arch perimeter associated with increases in arch width despite its interest and clinical usefulness. Germane *et al.* (1991) compared quantitatively the effects of expansion on mandibular arch perimeter using a mathematical model. Whilst this method can estimate changes in arch perimeter from increases in arch width, the tooth axis inclination associated with expansion cannot be derived. Germane *et al.* (1991) presented Ricketts' statement that 1 mm of inter-molar expansion increased the perimeter by 0.25 mm. According to the mathematical model developed by those authors, a 1 mm increase in inter-molar width results in an increase in arch perimeter of only 0.27 mm.

The present study intended to assess three-dimensionally the aspects of tooth movement associated with expansion. For this purpose, a 3D FEM and 3D graphic simulation were performed. The 3D simulation showed that a 1 mm increase in inter-molar width resulted in an increase in arch perimeter of 0.37 mm, indicating a greater value than that derived by Germane *et al.* (1991). This difference could be explained by the variations in calculation procedures. Germane *et al.* (1991) modelled the mandibular arch form with a two-dimensional spline function in order to calculate changes in arch perimeter associated with mandibular expansion. Despite the value stated by Ricketts being suggested as a guideline for development of a visual treatment objective, the method was not addressed (Germane *et al.*, 1991). In the present study, 3D aspects of tooth movement associated with expansion were evaluated, and an opening space between canine and first premolar on the 3D set-up simulation was regarded as an increase in dental arch perimeter.

When a force acts away from the centre of resistance, a moment is produced and a rotational tendency is induced (Mulligan, 1979). Tipping of a single root tooth by a single force produces a centre of rotation very close to the centre of the root. This means that the apex of the root moves forward while the crown moves back (Burstone, 1972). It is generally considered that a single force produces a centre of rotation located at a position within a range from one-half to one-third of the root apex (Burstone, 1972). Clinically, however, bone remodelling occurs and complex movements are produced.

The biomechanical consideration in the present study shows that the centre of rotation was located below the root apex. This result, differing from the general rule, may be due to the alveolar deformation simulated by the 3D FEM. The 3D simulation shows that a 1 mm (3.88 mm) increase in unilateral arch width results in a change in tooth axis of approximately 2.6 degrees.

Conclusions

3D set-up simulation was conducted in combination with a 3D FEM and 3D computer graphics technique in order to determine the increases in arch perimeter associated with an increase of arch width and changes in tooth axis. The following conclusions were reached:

1. 3D simulation showed that 1 mm of intermolar expansion increased the perimeter by 0.37 mm.
2. A 1 mm increase in unilateral arch width resulted in a change in tooth axis of approximately 2.6 degrees.
3. The above values would be useful when estimating the effects of mandibular expansion.

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