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Evaluation of stress changes in the mandible with a fixed functional appliance: A finite element study

Anshul Chaudhry,[a] Maninder S. Sidhu,[b] Girish Chaudhary,[c] Seema Grover,[d] Nimisha Chaudhry,[e] and Ashutosh Kaushik[f]

Ludhiana, Punjab, Gurgaon and Rohatak, Haryana, and Moradabad, Uttar Pradesh, India

Introduction: The aim of this study was to evaluate the effects of a fixed functional appliance (Forsus Fatigue Resistant Device; 3M Unitek, Monrovia, Calif) on the mandible with 3-dimensional finite element stress analysis. **Methods:** A 3-dimensional finite element model of the mandible was constructed from the images generated by cone-beam computed tomography of a patient undergoing fixed orthodontic treatment. The changes were studied with the finite element method, in the form of highest von Mises stress and maximum principal stress regions. **Results:** More areas of stress were seen in the model of the mandible with the Forsus compared with the model of the mandible in the resting stage. **Conclusions:** This fixed functional appliance studied by finite element model analysis caused increases in the maximum principal stress and the von Mises stress in both the cortical bone and the condylar region of the mandible by more than 2 times. (Am J Orthod Dentofacial Orthop 2015;147:226-34)

The aim of orthodontic treatment of children with malocclusions is to produce a well-balanced facial profile and an acceptable occlusion. Despite good treatment planning and patient selection, facial esthetics may not be ideal, and this can be compounded by relapse after an initially successful treatment. Dentofacial orthopedists believe that functional appliances train patients in maintaining correct oral and tongue postures. In the treatment of Class II malocclusion, an early phase of functional appliance treatment is commonly used to simplify subsequent therapy and to optimize the development of the facial skeleton.

McNamara[1] reported mandibular retrusion as the most common characteristic of Class II malocclusion. Class II Division 1 malocclusions with mandibular deficiency have been treated for more than a century with different types of functional appliances. Woodside et al,[2] Stockli and Willert,[3] Vargervik and Harvold,[4] and Ruf and Pancherz[5] stated that typical muscular forces are generated by altering the mandibular position sagittally and vertically, resulting in orthodontic and orthopedic changes. The pressure created by stretching of the muscles and soft tissues is transmitted to the dental and skeletal structures, moving the teeth and modifying growth.

Many removable functional appliances, such as activator, bionator, Fränkel, and Twin-block, have been used to correct Class II Division 1 malocclusions; however, few fixed functional appliances have been used. These fixed functional appliances for sagittal advancement of the mandible have certain advantages over removable functional appliances, such as less dependence on patient compliance, and these can be used concurrently with fixed mechanotherapy, thereby reducing treatment duration.[3] Fixed functional appliances also enhance mandibular growth and tend to produce more horizontal condylar growth compared with removable appliances.[6-8]

The theoretical basis of functional treatment in general is the principle that a new pattern of function

[a]Senior lecturer, Department of Orthodontics, Christian Dental College, Christian Medical College, Ludhiana, Punjab, India.
[b]Director, postgraduate studies; professor and head, Department of Orthodontics, Shree Guru Gobind Singh Tricentenary Dental College, Hospital and Research Institute, Budhera, Gurgaon, Haryana, India.
[c]Senior lecturer, Department of Orthodontics, Baba Jaswant Singh Dental College, Hospital & Research Institute, Ludhiana, Punjab, India.
[d]Professor, Department of Orthodontics, Shree Guru Gobind Singh Tricentenary Dental College, Hospital and Research Institute, Budhera, Gurgaon, Haryana, India.
[e]Formerly, postgraduate student, Department of Prosthodontics, Kothiwal Dental College, Moradabad, Uttar Pradesh, India.
[f]Private practice, Rohatak, Haryana, India.
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Address correspondence to: Anshul Chaudhry, Department of Orthodontics, Christian Dental College, CMC, Ludhiana-141010, Punjab, India; e-mail, dr.anshulchaudhry@gmail.com.
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dictated by the appliance leads to the development of a correspondingly new morphologic pattern. This new pattern of function developed by wearing of functional appliances refers to different functional components of the orofacial system, including the tongue, lips, and facial and masticatory muscles: mainly the protracting muscles, ligaments, and periosteum. The new morphologic pattern includes a different arrangement of the teeth in the jaws, improvement of the occlusion, and an altered relationship of the jaws.

The forces produced by the muscle contractions are transmitted to selected teeth and their periodontia, the jaws, and the temporomandibular joints. Anterior displacement of the mandible can induce altered postural activity in the pterygoid muscles, resulting in additional condylar growth.[9]

Removable functional appliances have some disadvantages; they are normally large, have unstable fixation, cause discomfort, lack tactile sensibility, exert pressure on the buccal mucosa, reduce space for the tongue, cause difficulty in deglutition and speech, and often affect the esthetic appearance. The lack of success with functional appliances has in some circumstance been attributed to a lack of patient compliance in wearing the appliance. This led to the development of fixed functional appliances.

Fixed functional appliances—more appropriately termed "noncompliant Class II interarch correctors"—have gained significant ground. A fixed appliance is aimed at targeting the dentition and providing the following dental corrections: facilitating mandibular advancement by eliminating dental interferences, and consolidating the arches to minimize the adverse dental side-effects. A number of fixed functional appliances have gained popularity in recent years to help achieve better results in noncompliant patients: eg, the Herbst appliance and the Forsus Fatigue Resistant Device (3M Unitek, Monrovia, Calif). Remodeling changes in the condylar head and glenoid fossa been reported after functional appliance treatment for correction of Class II skeletal dysplasia with mandibular retrognathia. The posterior displacement of the condylar head and the anterior relocation of the glenoid fossa with functional appliances have been confirmed with numerous radiologic techniques.[2,3,10-15]

The remodeling changes in the condyle and dentofacial complex have been studied routinely with cephalometric analysis.[16,17] The study of functional appliances using computed tomography has shown a double contour on the bony outline of the condylar head and fossa articularis,[18] whereas single photon emission computerized tomography scans of the temporomandibular joint (TMJ) showed significant increases in bone count, indicating increased bone formation in the TMJ after mandibular anterior repositioning splint treatment.[19] Magnetic resonance imaging studies have also shown that the mandibular condyle experiences tensile stresses in the posterosuperior aspect that explain condylar growth in that direction, whereas on the glenoid fossa, similar kinds of stresses are created in the posterior connective tissue region and are correlated with the increased cellular activity.[17] The recent use of cone-beam computed tomography (CBCT) in creating the 3-dimensional (3D) model of the dentofacial skeleton has enhanced the precision and understanding of the region.[20,21]

The biomechanical response of bone to orthopedic forces is quite complex. The use of the finite element method (FEM) initially in medical orthopedics and later in dentistry, especially orthodontics, allowed precise analysis of the biomechanical effects of various treatment modalities. The FEM, which has been successfully applied to the study of stresses and strains in engineering,[22,23] makes it possible to evaluate biomechanical components such as displacements, strains, and stresses induced in living structures from various external forces.[24-27] The first finite element models described the tooth-bone structure 2 dimensionally using average geometric relationships and homogeneous and isotropic material models. The 3D finite element models were later introduced in 1973 by Farah et al.[28]

The FEM has numerous advantages in orthodontics.[29] It is a noninvasive technique that measures the actual amount of stress experienced at any point on teeth, alveolar bones, periodontal ligaments, and craniofacial bones. It possibly can simulate the oral environment in vitro; the displacement of the tooth can be visualized graphically. The point of application, magnitude, and direction of a force may easily be varied to simulate the clinical situation; reproducibility does not affect the physical properties of the involved material, and the study can be repeated as many times as the operator wishes. Thus, the FEM has been introduced in orthodontics as a powerful research tool for solving various structural biomechanical problems.

The FEM analyzes the biomechanical effects of various treatment modalities and is an approximation method to represent both the deformation and the 3D stress distribution in bodies that are exposed to stress.

A pattern of stresses is created in the TMJ and orofacial complex when the mandible is protracted with a functional appliance. Whether this pattern remains the same during treatment and whether all biologic tissues respond in a similar predictable manner over time are not known. Previous FEM studies of functional appliances were on skulls or artificial models. Recently, Gupta