AJO-DO

Analysis of dentoalveolar structures with novel corticotomy-facilitated mandibular expansion: A 3-dimensional finite element study

Deepal Haresh Ajmera,[a] Pradeep Singh,[b] Chao Wang,[c] Jinlin Song,[a] Shui Sheng Xiao,[d] and Yubo Fan[e]
Chongqing and Beijing, China

Introduction: Surgically assisted mandibular arch expansion is an effective treatment modality for alleviating constriction and crowding. However, only mandibular symphyseal osteotomy is recommended for mandibular arch expansion. No relevant studies have compared the biomechanical responses of different corticotomy designs on mandibular expansion. Therefore, the aim of this study was to evaluate the effect of different corticotomy approaches and modes of loading on the expansion of adult mandibles using biomechanics. **Methods:** Nine finite element models including 2 novel corticotomy designs were simulated. Stress, strain, and displacement of crown, root, and bone were calculated and compared under different corticotomy approaches and loading conditions. **Results:** The biomechanical response seen in the finite element models in terms of displacement on the x-axis was consistent from anterior to posterior teeth with parasymphyseal step corticotomy and tooth-borne force application. In addition, the amount of displacement predicted by parasymphyseal step corticotomy in the tooth-borne mode was greater compared with other models. **Conclusions:** These results suggest that parasymphyseal step corticotomy with tooth-borne force application is a viable treatment option for true bony expansion in an adult mandible. (Am J Orthod Dentofacial Orthop 2017;151:767-78)

A tooth size-arch length discrepancy is a common form of malocclusion seen in clinical practice. Clinical characteristics including decreased mandibular arch length, narrow intercanine width, mandibular anterior teeth crowding, and posterior buccal crossbite are associated with transverse mandibular deficiency.[1,2] Moreover, from the treatment aspect, it is often believed to be a critical factor in decision making for surgical or nonsurgical expansion.

Compared with maxillary deficiency, transverse mandibular deficiency has received little attention from researchers recently. A variety of nonsurgical methods including the Schwarz and bihelix appliances have been used, with limited dimensional change and questionable long-term stability.[3-8] Expansion of the mandibular arch reported in these studies was localized to alveolar bone and mostly resulted in inclination of the teeth, without changes in the mandibular body. Moreover, a compromised periodontium caused by excessive dental expansion and proclination in addition to compromised facial esthetics have been noticed as disadvantages for such treatments. However, the results of combined surgical and orthodontic treatment for adults requiring an

[a]Chongqing Key Laboratory of Oral Diseases and Biomedical Sciences; Chongqing Municipal Key Laboratory of Oral Biomedical Engineering of Higher Education; Department of Orthodontics and Dentofacial Orthopedics, College of Stomatology, Chongqing Medical University, Chongqing, China.
[b]Chongqing Key Laboratory of Oral Diseases and Biomedical Sciences; Chongqing Municipal Key Laboratory of Oral Biomedical Engineering of Higher Education; Department of Oral and Maxillofacial Surgery, College of Stomatology, Chongqing Medical University, Chongqing, China.
[c]College of Stomatology, Chongqing Medical University; Chongqing Key Laboratory of Oral Diseases and Biomedical Sciences, Chongqing, China.
[d]Department of Oral and Maxillofacial Surgery, College of Stomatology, Chongqing Medical University, Chongqing, China.
[e]Laboratory for Biomechanics and Mechanobiology of Ministry of Education, School of Biological Science and Medical Engineering, Beihang University, Beijing, China.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Supported by the Program for Innovation Team Building at Institutions of World Health Organization Education in Chongqing, the Program for Innovation Team Building at Institutions of Higher Education in Chongqing in 2013, the National Clinical Key Specialty Constitution Program of China for 2013-2014, the National Natural Science Foundation of China (grant number 11402042), and the Scientific Research Foundation of Chongqing (grant number cstc2015jcyjA10027).
Deepal Haresh Ajmera and Pradeep Singh contributed equally to this study and are joint first authors.
Address correspondence to: Jinlin Song and Chao Wang, Chongqing Key Laboratory of Oral Diseases and Biomedical Sciences and College of Stomatology, Chongqing Medical University, Chongqing 400016, China; e-mail, 37112882@qq.com; soongjl@163.com.
Submitted, February 2016; revised and accepted, September 2016.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2016.09.015

increase in the lateral dimension have shown promising results. Recent reports have shown that corticotomy-assisted orthodontic treatment is a well-accepted option with a predictable outcome that offers solutions to many limitations associated with orthodontic treatment.

The first evidence of application of corticotomy in orthopedics comes from the early 1900s.[9] Since then, corticotomy-assisted orthodontic treatment has been used as an effective treatment alternative for the correction of various dentoalveolar discrepancies.[10-13] A patented technique called accelerated osteogenic orthodontics was also introduced by Wilcko et al[14,15] in this regard. Corticotomy-assisted orthodontic treatment involves selective alveolar decortication to induce a state of increased tissue turnover that is followed by faster tooth movement, resulting in reduced treatment time. In addition, corticotomy-assisted orthodontic treatment offers other advantages such as safer expansion of constricted arches and enhanced postorthodontic treatment stability.

Three-dimensional (3D) finite element (FE) analysis is a contemporary research tool for numeric simulation of mechanical processes of a real physical system that offers several advantages, including accurate representation of complex geometries and easy model modification.[16] Also, it is considered a valid and reliable approach for quantitative evaluation of stress-strain and displacement in the dentoalveolar structures.[17] Moreover, it provides the freedom to simulate orthodontic force systems applied clinically, in addition to evaluation and prediction of the dentoalveolar response to the mechanical loads in 3D spaces, thereby limiting the number of animal experiments.

The physiologic characteristics of bone to adapt to the mechanical environment when subjected to mechanical load by means of 2 inherent mechanisms—bone modeling and bone remodeling—are well known. Moreover, the concept of selective decortications followed by increased tissue turnover and transient osteopenia might be implied for correction of transverse mandibular deficiency. Hence, it can be hypothesized that with the change in the design of corticotomy, accompanied by different modes of force application, the biomechanical response of the bone tissue might change, and advanced mandibular expansion can be achieved that further contributes substantially to better treatment outcomes. With this intent, this study was aimed to compare the biomechanical effects of different modes of force application on 3 corticotomy designs and to select an optimal approach for clinical adoption with respect to a corticotomized mandible. Although a number of studies have used the FE method to investigate the biomechanics and mechanobiology of mandibular symphyseal osteotomy, to the best of our knowledge, this is the first study of its kind, comparing 3 corticotomy cuts including 2 novel corticotomy approaches with different modes of force application using the FE method.

MATERIAL AND METHODS

A cone-beam computed tomography scan projection of an adult mandible was obtained from the Department of Oral and Maxillofacial Radiology, College of Stomatology, Chongqing Medical University, in Chongqing, China. This scan (slice thickness, 1 mm; pixel size, 0.42 mm) served as the pattern for construction of the mathematical model. Processing of the data was performed using Mimics software (version 9.0; Materialise, Leuven, Belgium). The generated DICOM file was imported into the Mimics software for semiautomatic edge detection, followed by meshing of surface elements using an automated meshing module (Geomagic Studio; Geomagic, Morrisville, NC) to construct the 3D analytical model of the mandible and dentition through thresholding, region growing, and calculating 3D operations. The study protocol was approved by the ethics committee of Chongqing Medical University, and informed consent was obtained from the subject before the study.

With the help of Rapidform software (version 6.5; INUS, Seoul, Korea), we performed scaling and Boolean operations on the surface model of individual teeth and mandibular bone to produce cortical bone, trabecular bone, and periodontal ligament with average thicknesses of 2.0, 2.0, and 0.2 mm, respectively, thereby creating parametric solids from 3D scans. For the purpose of generating the geometric model, 5 materials including teeth, mucosa, trabecular bone, cortical bone, and periodontal ligament were assembled; they were assumed to be linearly elastic, homogeneous, and isotropic as shown in Figure 1. Furthermore, the orthodontic appliances and miniscrew implants were designed and modeled in CAD software (Solid Works, Dassault Systems, Concord, Mass). All components were saved in initial graphics exchange specification format and imported into ANSYS (Swanson Analysis Systems, Houston, Tex).

The constructed model was then exported to the FE software ANSYS, which divided the geometric model into finite elements; these elements were connected to adjacent elements by nodes, thereby creating a numeric representation of the geometric model. Table 1 gives the types and numbers of elements and nodes. Furthermore, to simulate the temporomandibular joint (TMJ), 2 blocks of temporal bone were made, and the space between temporal bone and condyles was filled by a 2-mm thick layer of articular disc. With regard to boundary conditions for the TMJ, constraints were placed on the 2