Journal of the World Federation of Orthodontists xxx (2018) 1–5

Contents lists available at ScienceDirect

Journal of the World Federation of Orthodontists

journal homepage: www.jwfo.org

Three-dimensional stress analysis with two molar protraction techniques using Finite Element Modeling

Mostafa A. Mohammed [a], Kareem M. Mohamed [b,*]

[a] Assistant Lecturer, Orthodontic Department, Faculty of Dentistry, Minia University, Al Minia, Egypt
[b] Lecturer, Orthodontic Department, Faculty of Dentistry, Minia University, Al Minia, Egypt

ARTICLE INFO

Article history:
Received 9 April 2018
Received in revised form
17 June 2018
Accepted 19 July 2018
Available online xxx

Keywords:
molar protraction
molar mesialization
FEM
mini-screw

ABSTRACT

Objective: To analyze the stresses induced during molar protraction while using temporary anchorage device and closed coil spring.
Materials and methods: Two finite element models (FEMs) of the maxilla were created using cone-beam computed tomography data from a dry skull. A three-dimensional model of teeth was obtained from drawing it with ideal length and width. Mini-screw (1.5 × 8.0 mm) was inserted in the buccal zone distal to upper second premolar in one model. Load (150 g) was applied to the stainless-steel arm from the molar band and head of the mini-screw in model 1, and in model 2, load was applied to the stainless-steel arm from the molar and premolar bands.
Results: In model 1, high stresses were found at the head of the mini-screw and stainless-steel arm of molar band and average stresses were found in roots of upper permanent molar. Whereas in model 2, high stresses were found in both stainless-steel arm of molar and premolar bands and average stresses were found in peri-alveolar area of upper second molar and premolar.
Conclusion: Molar protraction with mini-screw anchorage produces higher stresses at head of mini-screw that may affect its stability and can even lead to its fracture.

1. Introduction

Permanent first molar erupts early in the oral cavity. Accordingly, it has high risk of caries and decay. It was also claimed that it is the most commonly missing tooth in adults [1]. There are multiple treatment choices to restore this missing tooth with either a fixed partial denture or an endo-osseous dental implant [2]. In orthodontics, the first permanent molar is considered the key of occlusion. The loss of this tooth leads to several problems, including malocclusion, arch asymmetry, drifting of adjacent teeth to the extraction space and temporomandibular disorders. The most accepted orthodontic treatment method to deal with missing permanent first molar is to substitute it with second permanent molar if adequate anchorage is established to prevent unwanted side effects in anterior segment [3–6].

A temporary anchorage device (TAD) is fixed to bone for enhancing orthodontic anchorage by supporting the teeth of the reactive unit or by obviating the need for the reactive unit all together, and which is subsequently removed after use [7]. Molar protraction is considered as a biomechanical method used to close the space present after loss of the first permanent molar. Many studies were performed to evaluate the efficiency of molar protraction as a substitution of missing first molar either by using TADs or other methods, but there was nothing reported to evaluate the stresses produced when using TADs or using anterior segment as an anchorage [8–11]. Finite element method (FEM) is a numerical analytic method used to predict the effect of stresses on complex structures such as dental structures. Also, it allows a close simulation of the component of the dental structure under investigation; thus, providing an accurate presentation of the stress behavior in the object being examined [12]. This study investigated the stresses induced due to the application of force with different anchorage design. Furthermore, analyses of the stress applied from protraction mechanics at the posterior area with different anchorage design were also evaluated.

2. Materials and methods

The finite element analysis, designed in this study, simulated a clinical situation: an upper permanent second molar that should be protracted to the extraction space of the permanent first molar

* *Corresponding author:* Orthodontic Department, Faculty of Dentistry, Minia University, Al Minia, Egypt 6111. (K.M. Mohamed).
E-mail address: kemosuns@gmail.com (K.M. Mohamed).

2212-4438/$ – see front matter © 2018 World Federation of Orthodontists.
https://doi.org/10.1016/j.ejwf.2018.07.004

either by pulling with closed coil spring attached on a hook welded on the second premolar anteriorly or attached on mini-screw (TAD) fitted distal to the root of the second premolar. Two models were constructed with the following differences:

1. A model representing dry skull with permanent dentition and band cemented on the upper second molar and upper second premolar.
2. Another model was constructed like the first one but with mini-screw inserted distal to the root of the second premolar.

The two analytical models were selected and scanned by cone-beam computed tomography scanner (CBCT; GX CB-500, powered by i-CAT, Broomfield, CO) to get the ideal geometrical outline. Mimics software program (MIMICS 10.01 for Intel x86 platform v10.2.1.2; Materialise NV, Leuven, Belgium) was used to edit and crop the CBCT images. Three-dimensional drawing of the model components was done by tracing every CBCT cut in the Solidworks software program (Solidworks 2013 software; Dassault Systemes, Velizy-Villacoublay, France) to produce a three-dimensional (3D) model of the maxilla. A 3D model of teeth was obtained from drawing the teeth according to the ideal length and width of every tooth. Assembling of different components with each other (bone and teeth, bone and screw, and teeth and bands) was carried out to collect all parts of each model. (Fig. 1). The material properties for spongy bone, titanium alloy, stainless-steel alloy, teeth, and ligaments were identified [13,14] (Table 1).

The models were restrained at the back and superior border to avoid total body displacement. Mini-screw (1.5 × 8 mm) was inserted in the buccal zone distal to the upper second premolar in one model. Load (150 g) was applied to the stainless-steel arm in the molar band and head of the mini-screw in model 1 and applied to the stainless-steel arm in molar band and premolar band in model 2 (Fig. 2A and C). The models were meshed with a curve-based solid mesh (Fig. 2B and D). The stresses at the maxillary sinus floor, nasal cavity floor, roots of upper second permanent molar, the screw (head and body), connecting arm, and peri-alveolar area of the upper second premolar were measured.

3. Results

To calculate the mean stress at the specific areas in the model, every area of measurement was represented by 10 equally distributed points with equal intervals. Every point was measured and the mean was calculated to get overall stress in the target area. All stress values were measured in Mega Pascal (Mpa) units and are provided in Table 2.

4. Discussion

Stress analysis studies have been widely used to provide good understanding of the nature of the stresses acting on the dental structures [15]. Finite element analysis solves a complex problem by redefining it as the summation of the solution by a series of interrelated simpler problems. The first step is to subdivide the complex geometry into a suitable set of smaller “elements” of “finite” dimensions, which are further combined to form the “mesh” model of the investigated structures. Each element can adapt a specific geometric shape (i.e., triangle, square, tetrahedron, and the like) with a specific internal strain function. Using these functions and the actual geometry of the element, the equilibrium equations between the external forces acting on the element and the displacements occurring on its nodes can be determined [16].

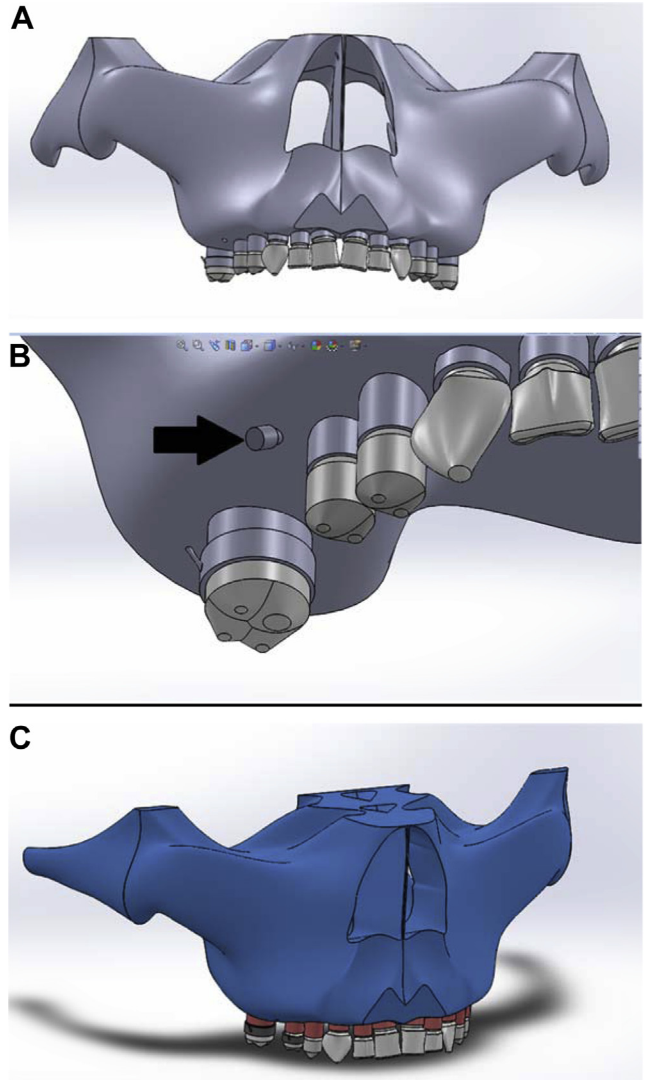

Fig. 1. (A) Final model 1 with teeth, molar band, stainless-steel arm, and hole for mini-screw. (B) Model 1 after mini-screw insertion. (C) Model 2 with teeth, molar and premolar bands, and stainless-steel arms.

To exclude any unwanted structure of maxilla and simplify the complex structures of the maxilla, CBCT cuts were prepared from a dry skull following the previous research using CBCT and dental CT to make 3D models [17–19]. CBCT helped us to provide area of focus in images with missing first molars with no blurring and 1:1 magnification. Tracing every picture into a solid work program was carried out by spline feature to record any fine details of the model. Any teeth presented in the analytical model were eliminated from the model and the full arch dentition was drawn by the ideal

Table 1
Elastic properties of materials used in studies

Material name	Modulus of elasticity, Mpa	Density, kg/m^3	Yield strength, N/mm^2	Poisson's ratio
Spongy bone	13,700	1900	170	0.3
Teeth	22,000	1020	371.6	0.3
Band	210,000	7700	620.42	0.3
Mini-screw	117,000	4428.78	750	0.33
Ligament	1.18	1100	2	0.45

Please cite this article in press as: Mohammed MA, Mohamed KM, Three-dimensional stress analysis with two molar protraction techniques using Finite Element Modeling, Journal of the World Federation of Orthodontists (2018), https://doi.org/10.1016/j.ejwf.2018.07.004