International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 9 (2016) pp 6794-6799

Determination of Displacements in the Biomechanical Orthodontic System by Using Finite Element Method

Kadry Ali Ezzat*
Assistant Lecturer, Biomedical Engineering Department,
Higher Technological Institute, 10th of Ramadan City, Egypt.

Dr. Ahmed H. Kandil
Associate Professor, Biomedical Engineering and Systems Department,
Faculty of Engineering, Cairo University, Giza, Egypt.

Dr. Sahar Ali Fawzi
Associate Professor, Biomedical Engineering and Systems Department,
Faculty of Engineering, Cairo University, Giza, Egypt.

Prof. Dr. Ahmed M. El-Bialy
Professor, Biomedical Engineering and Systems Department,
Faculty of Engineering, Cairo University, Giza, Egypt.

Abstract

Orthodontic tooth movement is a physiologic reaction to remotely connected forces; intention forces are principally mechanical. The ideal use of orthodontic force empowers most extreme movement of teeth with the negligible irreversible harm of the alveolar bone, and teeth. Since Archwires are the primary power framework in orthodontics, it is imperative in clinical practice that they convey suitable, predictable and repeatable forces amid treatment.

These specific wires even guarantee shape memory properties and the likelihood of super elastic behaviour, which fundamentally affects clinical practices. Since, Titanium, Nickel and Cobalt Archwires are still the materials of decision in numerous phases of treatment. They provide an alluring blend of stiffness, flexibility and formability.

In any case, clinical specialists have remarked on the variability of Archwire behaviour for quite a long time. Conflicting Archwire properties can add to eccentric treatment term and results.This paper analyzes the mechanical and physical attributes of Titanium, Nickel and Cobalt wires to evaluate their variability in engineering terms. From the outcomes for those sorts of wires, the testing technique gives the data required by originators wishing to enhance the Archwires properties and provide important data to clinicians for their practice.

Keywords: orthodontics, mechanical properties, tensile properties, orthodontic wires, titanium, stainless steel.

Introduction

Malocclusion is the misalignment of teeth, or when the relationship between the upper and lower dental curves is off base. Malocclusions happen in every one of the three planes of space and can influence every tooth in each of the three planes. All out malocclusion recurrence shifts with a mean of 46% [1]. Of all malocclusions, crowding is the overwhelming intra-curve issue in patients looking for orthodontic treatment in the United States and Western Europe [2] [3].So as to right malocclusions orthodontic treatment is required.The favored treatment choice in the remedy of malocclusions is the usage of fixed orthodontic appliances. Contemporary orthodontics depend on the utilization ofto fathom the misalignment of teeth and bite issues by moving the teeth step by step into the ordinary position in the dental curve. The fixed orthodontic appliance comprises of sections that are attached to the teeth, and orthodontic wires.At the point when the wire is occupied with the slot of the brackets it produces the forces necessary for orthodontic tooth movement [4] [5] [6]. Important for orthodontic tooth development [4] [5] [6]. Every tooth is connected to the alveolar bone by a solid system of parallel collagen strands.

The grouping of occasions completed by applying forces inside the cutoff points of physiological resilience starts with the diminished blood course through the PDL, trailed by the resorption and the juxtaposition of the bone.

The bone that contradicts the movement experiences frontal resorption to take into consideration dental uprooting, though on the inverse side, the anxiety of the periodontal filaments results in the testimony and the creation of another bone.

On the off chance that orthodontic forces stay light, frontal resorption on one side and pairing of the other will happen at the same rate [8].

At the point when a power of extraordinary force is connected to the tooth, it causes a vascular impediment and slices the blood supply to the PDL [9].

in this situation, aseptic corruption happens, bringing about an undermining bone resorption that does not begin from the dental side, but rather originates from the alveolar area, creating the tissue harm, hyalinization and agony [10].The procedure of fundamental resorption is speedier and all the more harming contrasted with frontal resorption [11] [12]. So as to avoid undermining resorption light forces ought to be utilized amid orthodontic treatment.The ideal force utilized as a part of orthodontic treatment ought to be sufficient to deliver tooth movement without tissue harm and withmost extreme solace for the patient.Extreme forces can prompt serious agony, harm of the periodontal ligament and root resorption [13]. Inadequate forces amplify the term of the treatment.Conveying idealforce levels for controlling tooth movement stays absolutely critical amid orthodontic treatment.

Light nonstop orthodontic forces are favored. The force expected to move the tooth is distinctive for every tooth and relies on upon the sort ofmovement that is required amid orthodontic treatment [14] For instance; Optimumforce level of tooth movement more often than not fluctuates in the scope of 0.09 to 1 N.

An assortment of wires is utilized to produce the essential biomechanicalforces associated with tooth movement, for example, Titanium; Cobalt; and Nickel.Once the wire is actuated or twisted, it is the emptying or deactivatingforces that deliver the orthodontic tooth movement. With current orthodontic treatment Titanium; Cobalt; and Nickel wires are frequently utilized because of their predominant mechanical properties, biocompatibility, pliability, imperviousness to erosion, lower elastic modulus, and unique attributes, for example, super flexibility and shape memory impact.

The impact that the wire produces is a rundown of properties of the wire itself and geometrical components. Geometrical variables, for example, the cross-segment of the wire (round, rectangular) and the separation between the brackets, greatly affect theforce level. These elements ought to be tended to when the extent of orthodonticwhen the extent of orthodontic force is measured. There is still deficient learning of the bearing, magnitude and appropriation of the forces applied in orthodontic treatment, as well as their impact on the tooth and encompassingstrong structures. As of not long ago, a significant part of the orthodontic biomechanics writing was confined to 2-dimensional exploratory investigations of the biomechanical parts of orthodonticforce frameworks [15] and all the more as of late, to 3-dimensional (3D) computer modelling [16]. There is little proof with respect to 3D trial estimations and examination of orthodontic force frameworks [17]. Arrangements utilizing numerical strategies started after 1970, prompting the advancement of particular programming bundles. Research directed bythe finite element method (FEM) in dental practice has been connected essentially to dental implants[18], stress in periodontal ligaments and displacements of teeth affected by outer forces [19].

The FEM empowers the examination of the biomechanical issues included in orthodontic treatment. What's more, it empowers right now expanded exploratory enthusiasm for toothmovement [20]. The improvement of a numerical model makes it conceivable to measure and assess the impacts of orthodontic loads applied keeping in mind the end goal to accomplish tooth movement.

One of the fundamental components of the FEM lies in its capability to investigate complex structures.On account of tooth movement, the numerical model ought to take after the clinical setting, including the sort of malocclusion and decision of sections, and in addition curve wires.

Simulation of orthodontic tooth movement with a settled orthodontic appliance using FEM can help as a part of the determination of the forces created by the orthodontic wire.The motivation behind this article was tosimulate the displacements on the orthodontic framework on account of respectably packed frontal teeth in the lower dental curveand to measurethe stresses applied to the teethwhen distinctive wires were occupied with altered orthodonticappliances.

Materials and Methods Model

CT scanning and 3D reconstruction

Computerized Tomography (CT) images for real skulls of patients were taken at 0.5 mm intervals, the DICOM data was saved, then mandible data was segmented from skull data using (algorithm) then 16 teeth were segmented completely from the mandible as shown and reconstructed in three dimensions [21].After 3D reconstruction of 16 teeth, each tooth segmented as shown in stored in STL file format as shown in Figure 1

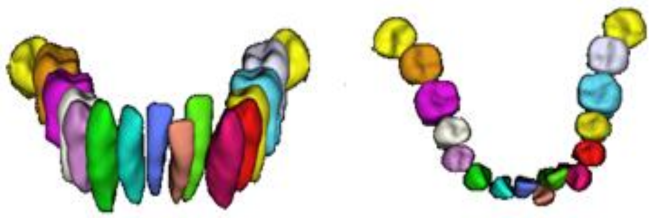

Figure 1: segmentation of each tooth in lower teeth

Design of the Orthodontic 3D Model

Teeth model

To generate the 3D finite element model, autoconverter software is used to convert each tooth STL file to Computer Aided Design (CAD) format where each STL tooth, which is surface model was imported into an autoconverter program to generate a CAD model as shown in figure2.

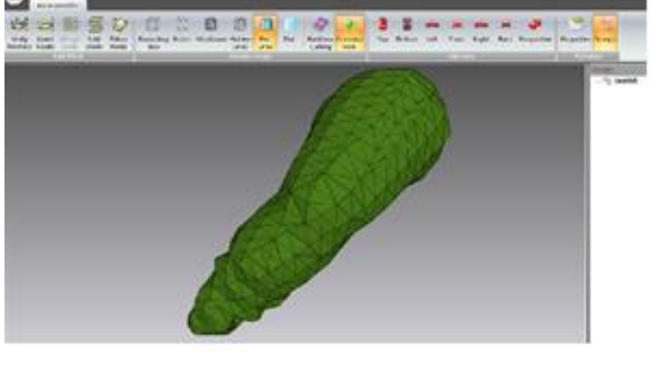

Figure 2: The conversion of STL Format to CAD Format

Assembly of teeth model with the other orthodontic 3D model components

The orthodontic 3D model for this study was built using the SolidWorks 2016 software. A 3D modelof16 teeth in the lower dental arch simulated real malocclusion.

An altered orthodontic appliance was utilized to simulate the orthodontic treatment in a situation with moderate swarming. Metal brackets were attached to the teeth and wire embedded into theslots. The teeth model was gone about as a genuine model with genuine measurements as indicated by the dental life systems literatures.

A 3D model of the lower 16 teeth with mandible was acquired. At that point the orthodontic wires with various materials were embedded into thebracket slot of every tooth in the model.For the model a wire of dimensions 0.7 mm X 0.7mm was taken into consideration. As shown in figure 3.

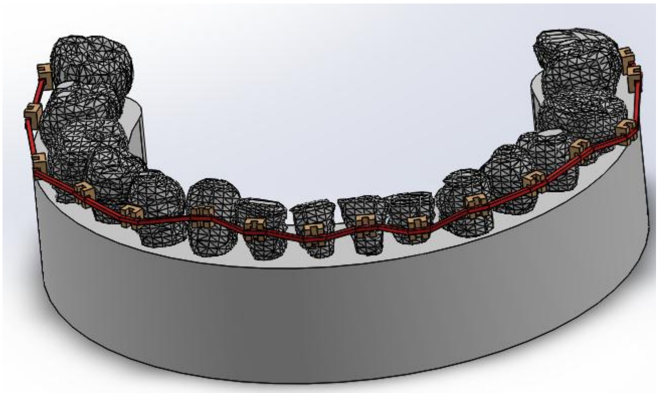

Figure 3: CAD model of tooth position with boundary conditions.

Material properties

In order to improve the model, materials were considered to be homogeneous, implying thatlinear and elastic material behaviour included two constants: Young's modulus and Poisson's ratio as shown in TABLE 1.

Table 1: Young's modulus and Poisson's ratio on separate segments of the orthodontic system

Linear-elastic material parameters used for:	Young's modulus of elasticity, E [MPa]	Poisson's ratio
Alveolar bone	13800	0.3
Teeth	20000	0.3
Bracket (stainless steel)	180000	0.3

The mechanical properties of natural tissues and orthodontic materials were obtainedfrom the orthodontic literature [22-23-24-25-26].

The properties are the input information required for the numerical model, which depends on the finite element method. The structures that make up this model are composed of organic tissues and metallic materials with various mechanical properties in terms of attributes and values, as following.

Teeth

In order to simplify the tooth structure as a solitary body to suit the fancied investigation, the values used to characterize tooth properties were: 20, 000 N/mm2 for the modulus of elasticity [27] [28] [29] and 0.30 for the Poisson's ratio. [30][31].

Bone

The dental alveolus is made out of a dainty layer of cortical bone, which discusses straightforwardly with the periodontal strands. Several authors depictit as a homogeneous and isotropic material with a linear and elastic behaviour. The mechanical properties found in the literature [30] [31] allocate to the alveolar cortical bone a mean estimation of 13, 800 N/mm2 (modulus of elasticity) and 0.30 (Poisson's ratio).

Brackets

Orthodontic brackets of dimension 3.02 mm X 3.02 mm with depth 2 mm are made of stainless steel and have characterized properties, for example, such as 180, 000 N/mm^2 [32] for the modulus of elasticity and 0.30 for the Poisson's ratio.

Arch wires

Orthodontic wires are made of Titanium, Nickel and Cobalt have characterized properties such as110000 N/mm^2, 210000 N/mm^2 and 211000 N/mm^2[32] for the modulus of elasticity and 0.30, 0.31 and 0.31for the Poisson's ratio as shown in TABLE 2.

Table 2: The material parameter of wires for COSMOSM model.

Material of the Wires	Young's modulus of elasticity, E [MPa]	Poisson's ratio
Titanium	110000	0.3
Nickel	210000	0.31
Cobalt	211000	0.31

Finite element model generation

The built model was moved into theCOSMOSM software for the numerical recreation by the FEM. In this model a static examination performed. The model is a settled one mounted in the alveolar bone. To simplify the numerical calculation the orthodontic wirealtered unbendinglyin the bracket of the teeth. A loadof 1 N was placed in the labial direction of the wire. With this sort of load the model nearer to the genuine case. The numerical model consists of 208951 finite elements, 316931 nodes and 914361 degrees of freedom as shown in figure 4

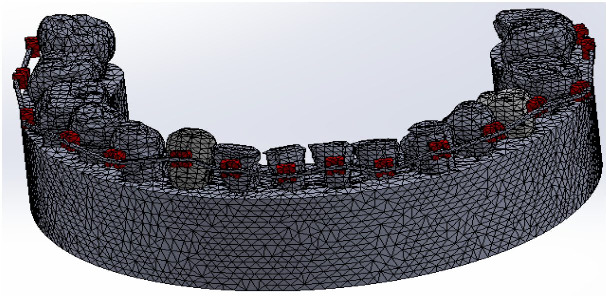

Figure 4: the finite element mesh of the model

Results and Discussions

By using COSMOSM software for numerical simulation a model with three different orthodontic wires was presented. The values of the displacements of tooth Canine produced by different types of wires are shown in Figures 5, 6 and 7. When applying a 1 N load (force) in labial direction, it can be seen that by increasing the value of elastic modulus of the wires, the displacement ofthe bracket and Caninedecreasing while the stresses increasing slightly to be as shown in figure 8.

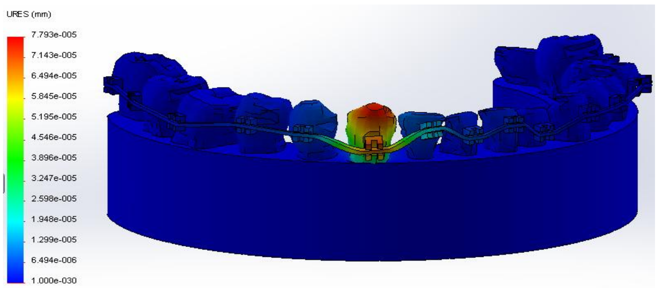

Figure 5: The displacement of titanium wire and Canine

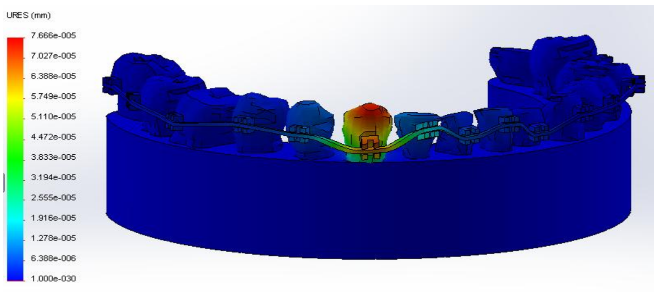

Figure 6: The displacement of Nickel wire and Canine

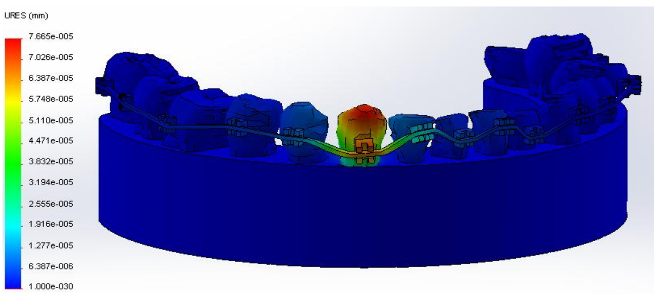

Figure 7: The displacement of Cobalt wire and Canine

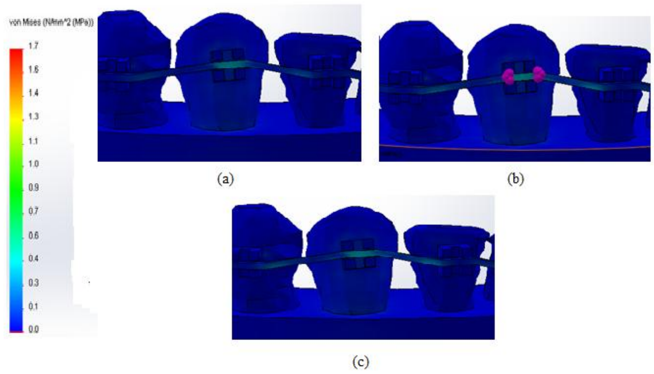

Figure 8: the stresses in Von Misses of (a) Titanium, (b) Nickel and (c) Cobalt

In Table 3the results observed of the displacement according to the stresses when an orthodontic force of 1 N was applied onthe wires. From titanium wire the maximum orthodontic displacement was obtained of 7.793e^{-005} mm and from Nickel wire the orthodontic displacement was 7.666e^{-005} mm while from Cobalt wire the minimum orthodontic displacement was obtained of 7.665e^{-005} mm as shown in TABLE 3 and Figure 9.

Table 3: The stresses and displacements of each wire.

Von-mises stress (N/mm^2)	Titanium Wire Displacement (mm)	Nickel Wire Displacement (mm)	Cobalt Wire Displacement (mm)
0.0	0.0	0.0	0.0
0.1	6.494 e^{-006}	6.388 e^{-006}	6.387 e^{-006}
0.3	1.299 e^{-005}	1.278 e^{-005}	1.277 e^{-005}
0.4	1.948 e^{-005}	1.916 e^{-005}	1.915 e^{-005}
0.6	2.598 e^{-005}	2.555 e^{-005}	2.555 e^{-005}
0.7	3.247 e^{-005}	3.194 e^{-005}	3.194 e^{-005}
0.9	3.896 e^{-005}	3.833 e^{-005}	3.832 e^{-005}
1.0	4.546 e^{-005}	4.472 e^{-005}	4.471 e^{-005}
1.1	5.195 e^{-005}	5.110 e^{-005}	5.110 e^{-005}
1.3	5.845 e^{-005}	5.749 e^{-005}	5.748 e^{-005}
1.4	6.494 e^{-005}	6.388 e^{-005}	6.387 e^{-005}
1.6	7.143 e^{-005}	7.027 e^{-005}	7.026 e^{-005}
1.7	7.793 e^{-005}	7.666 e^{-005}	7.665 e^{-005}

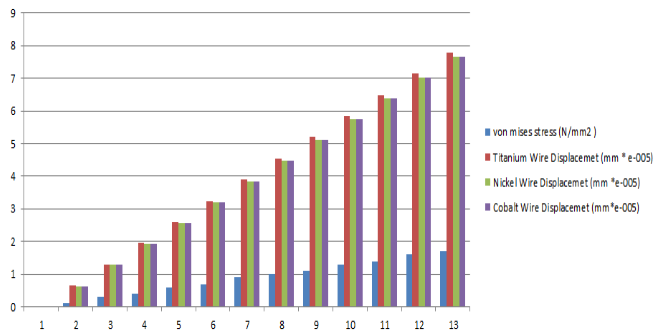

Figure 9: shows the relation between stresses and displacements of different wires

In this model of the orthodontic system, it observed that a Lower elastic modulus of wires gives a higher level of orthodontic displacements and lower level of stresses on the Canine.

FEM is anintense tool for the investigationof complex structures, however the result is reliant on the definition of the problem. The acting forces outset phase of orthodontic treatment for the situation with moderate swarming were exhibited utilizing FEM.This was an endeavor to measure and assess the impacts of orthodontic loads applied to the bracket and teeth, keeping in mind the end goal to accomplish startingtooth movement. With the goal of disentangling the technique the snippet of force was not considered.The accentuation was put on the level of force created by the Titanium, Cobalt and Nickel wires. It was resolved that, by the littlest elastic modulus of Titanium, the calculated displacement of the tooth was 7.793 e^{-005}mm. The lower displacement was produced by wires with a higher value of elastic modulus.

Diverse structures and materials utilized as a part of orthodontics have had their properties recognized, for example, bones, teeth and stainless steelbrackets. At the point when a numerical model is utilized to pick the right material properties, such as elastic modulus and Poisson's ratio, and in addition showing the attributes of the alveolar bone and teeth are the most essential elements in getting exact results.Additionally, the dependability of FEM can't be checked specifically, because of the way that the model of swarmed teeth was made just as an imitation of a genuine issue.

The extensive variety of limit conditions, contact definitions, material property definitions, and so on., utilized as a part of FEM investigations makes a certified requirement for consistency. Since the presentation of FEM into dental biomechanical research in 1973, the stress and strain fields in the alveolar bolster structures amid orthodontic tooth movement have been examined broadly. Very little research has been done in simulating the orthodontic movement concentrating on the properties of the orthodontic wire and its impact on supporting structures.The properties of wires made by various producers ought to be accessible to empower reenactment of the genuine issue. The further simulations must be more precise.. Consequently, research work in the future will concentrate on the determination of the elastic modulus of various commercially available orthodontic wires, and friction coefficients between wires and brackets, as well as other properties that define the orthodontic movement of the teeth.

The Contact focuses between single components, especially between wire and bracket, ought to be built correctly.The contact focuses between wire and bracket are spots of higher stress fixation and ought to be taken into consideration in determining the friction. Moreover, the force level delivered by the altered orthodontic appliance in various orthodontic instances of dental malposition should be measured and compared.

Conclusions

Ideal utilization of orthodontic wires can be made by via deliberately selecting the fitting wiretype and size to meet the requests of a specific clinical circumstance. The modulus of elasticity of the orthodontic wires was distinctive and can bring about huge computational mistakes inorthodontic appliance mechanics. Results demonstrated that, in general, dimensions, elastic moduli, Poisson'sratio areessential parameters for evaluating the mechanical properties and physical attributes between materials.

The testing strategies utilized show high reliability and the parameters chose for assessment to give the data that could be vital in the assessment and correlation of various wire types in future studies.

References

[1] ADANIR N., BELLI S., 2007, "Stress analysis of a maxillary central incisor restored with different posts, " Eur. J. Dent., 1(2), 67-71.

[2] ANUSAVICE K.J., 2003, Phillips' Science of Dental Materials, Elsevier Health Sciences.

[3] Li Z, Yang Z, Zuo L, Meng Y. A, 2014, "three-dimensional finite element study on anterior laminate veneers with different incisal preparations", J Prosthetic Dentistry;112:325-33.

[4] CHLADEK G., WRZUŚ-WIELIŃSKI M., 2010, "The evaluation of selected attachment systems for implant-retained overdenture based on retention characteristics analysis, " Acta Bioeng. Biomech., 12(3), 75-83.

[5] CORREIA A.R.M., FERNANDES J.C.S., CAMPOS J.C.R., VAZ M.A.P., RAMOS N.V.M., 2009, "Stress analysis of cantileverfixed partial denture connector design using the finite element method, " Rev. Odonto Ciênc., 24(4), 420-425.

[6] DĄBROWA T., DOBROWOLSKA A., WIELEBA W., 2013, "The role of friction in the mechanism of retaining the partial removable dentures with double crown system, " Acta Bioeng. Biomech., 15(4), 43-48.

[7] DOBRZAŃSKI L.A., REIMANN Ł., 2012, "Digitization procedure of creating 3D model of dental bridgework reconstruction, " JAMME, 55(2), 469-476.

[8] DORNHOFER R., ARNETZL G.V., KOLLER M., ARNETZL G., 2007, "Comparison of the static loading capacity of all-ceramic bridge frameworks in posterior teeth using three hard core materials, " Int. J. Comput. Dent., 10(4), 315-328.

[9] FAWZI S., 2013, "The effect of dental implant design on bone induced stress distribution and implant displacement, " Int. J. Comput. Appl., 74(17), 15-21.

[10] Cai YQ, Yang XX, He BW, Yao J. Numerical 2015, "analysis of tooth movement in different plans of transparent tooth correction therapies, " Technology and Health Care, 23:299-305.

[11] KERMANSHAH H., BITARAF T., GERAMY A., 2012, "Finite Element Analysis of IPS Empress II Ceramic Bridge Reinforced by Zirconia Bar, " J. Dent. (Tehran), 9(4), 196-203.

[12] LIN J., SHINYA A., GOMI H., SHINYA A., 2012, "Finite element analysis to compare stress distribution of connector of lithia disilicate-reinforced glass-ceramic and zirconiabased fixed partial denture, " Odontology, 100, 96-99.

[13] MILEWSKI G., HILLE A., 2012, "Experimental strength analysis of orthodontic extrusion of human anterior teeth, " Acta Bioeng. Biomech., 14 (1), 15-21.

[14] MOLLERS K., PATZOLD W., PARKOT D., KIRSTEN A., GUTH J.F., EDELHOFF D., FISCHER H., 2011, "Influence of connector design and material composition andveneering on the stress distribution of all-ceramic fixed dental prostheses: A finite element study, " Dent. Mater, 27, e171-e175.

[15] OH W.S., ANUSAVICE K.J., 2002, "Effect of connector design on the fracture resistance of all-ceramic fixed partial dentures, " J. Prosthet. Dent., 87(5), 536-542.

[16] ONODERA K., SATO T., NOMOTO S., MIHO O., YOTSUYA M., 2011, "Effect of connector design on fracture resistance of Zirconia all-ceramic fixed partian dentures, " Bull. Tokyo Dent. Coll., 52(2), 61-67.

[17] REZAEI A., HEIDARIFAR H., AREZODAR F., AZARY A., MOKHTARYKHOEE S., 2011, "Influence of connector width on the stress distribution of posterior bridges under loading, " J. Dent. (Tehran), 8(2), 68-74.

[18] ROMEED S.A., FOK S.L., WILSON N.H.F., 2004, "Finite element analysis of fixed partial denture replacement, " J. Oral. Rehabil., 31, 1208-1217.

[19] SAKAGUCHI R.L., POWERS J.M., Craigs, 2012, Restorative Dental Materials, Elsevier.

[20] ŻMUDZKI J, CHLADEK G, KASPERSKI J, DOBRZAŃSKI LA., 2013, "One versus two implant-retained dentures: comparing biomechanics under oblique mastication forces, " J. Biomech. Eng., 135 (5), DOI, 10.1115/1.4023985.

[21] Kadry Ali Ezzat, Ahmed H. Kandil, Sahar Ali Fawzi, 2016, "Novel Computerized System To Simulate Orthodontic Treatment Plan, "International Journal of Applied Engineering Research ISSN 0973-4562, Volume 11, Number 8, pp 5673-5681.

[22] Chen F, Terada K, Handa K. 2005, "Anchorage effect of various shape palatal osseointegrated implants: a finiteelementstudy, " Angle Orthod. May;75(3):378-85.

[23] Dorow C, Schneider J, Sander FG.2003, "Finite element simulation of in vivo tooth mobility in comparison with experimental results, " J Mech Med Biol. 3(1):79-94.

[24] Ferreira FV. 1996, "Ortodontia: diagnóstico e planejamento clínico, " São Paulo: Artes Médicas.

[25] Geramy A. 2002, "Initial stress produced in the periodontal membrane by orthodontic loads in the presence of varying lossofalveolarbone:a three-dimensional finite element analysis, " Eur J Orthod. 24(1):21-33.

[26] Geramy A, 2002, "Optimization of unilateral overjet management: three-dimensional analysisbythe finite elementmethod, "Angle Orthod, 72(6):585-92.

[27] Jeon PD, Turley PK, Ting K, 2001, "Three-dimensional finiteelement analysis of stress in the periodontal ligament of the maxillaryfirst molar with simulated boneloss, " Amj Orthod Dentofacial Orthop. 119(5):498-504.

[28] Katona TR, Qian H. 2001, "A mechanism of noncontinuous supraosseous tooth eruption, " Am J Orthod Dentofacial Orthop. 120(3):263-71.

[29] McCormack SW, Witzel U, Watson PJ, Fagan MJ, Gröning F, 2014, "The Biomechanical Function of Periodontal Ligament Fibres in Orthodontic Tooth Movement, " Plos one, 9:1-13.

[30] Rees JS, Jacobsen PH, 1997, "Elastic modulus of the periodontal ligament, " Biomaterials, 18(14):995-9.

[31] Rees JS, 2001, "An investigation into the importance of the periodontal ligament and alveolar bone as supporting structures in finite element studies, " J Oral Rehabil, 28(5):425-32.

[32] Tominaga JY, Ozaki H, Chiang PC, Sumi M, Tanaka M, Koga Y, et al, 2014, "Effect of bracket slot and archwire dimensions on anterior tooth movement during space closure in sliding mechanics: A 3-dimensional finite element study, " Am J Orthod Dentofacial Orthop, 146:166-74.