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Finite Element Analysis of Stress Distribution During Retraction of Mandibular Incisors

Nada M Al-Sayagh
BDS, MSc (Asst. Prof.)
Dept of Pedod, Orthod, and PrevDentistry
College of Dentistry, University of Mosul

Mohammad N Mahmood
PhD (Prof.)
Dept of Civil Engineering
College of Engineering. University of Mosul

Rasha Y Al-Darzi
BDS, MSc (Asst. Lec.)
Dept of Pedod, Orthod, and PrevDentistry
College of Dentistry, University of Mosul

الخلاصة

الأهداف: تهدف الدراسة الحالية للتعرف على توزيع الاجهاد والقوى على القواطع السفلية تحت تاثير قوى السحب التقويمية.**المواد وطرائق العمل**: تم استخدام طريقة التحليل بالعناصر المحددة في عملية السحب اللااحتكاكي للقواطع السفلية باستخدام الاسلاك التقويمية ذات انحناءات(Delta) من مادة(NiTi) ومادة (Stainless steel) بدون زاوية (Gable) واسلاك (Stainless steel) بزاوية (Gable).**النتائج**: ان تركيز القوى الضاغطة كان واضحا في نقطة تسليط القوى على طول خط عمل السلك التقويمي مع القواطع الاربعة. **الاستنتاجات**: توزيع الاجهاد الناتج من قوى السحب التقويمية لا يؤثر بصورة متساوية على القواطع الاربعة ماعدا في حالة السحب باستخدام اسلاك التقويم من نوع (NiTi) حيث اظهرت الاسنان حركة متساوية اثناء السحب.

ABSTRACT

Aims: The present study aimed to determine stress and strain distribution on the four lower incisors under the effect of (400g) calculated retracted orthodontic force. **Materials and methods:** Using finite element analysis method, frictionless retraction technique was successfully used with the aid of continuous (delta loop) on NiTi, Stainless steel wires without gable bends and stainless steel looped wire using 40°. gable bends(20° alpha, 20° beta gable) respectively. **Results:** High compressive stress concentration in labiolingual direction are observed near the point of force application and along the line of action of orthodontic wire at the crown of both lateral and central incisors. **Conclusions:** The stress distribution is not the same for the all retracted segment and there was independent movement of lateral incisors from the central incisors except for the retraction using NiTi wires which exhibits uniform movements for both lateral and central incisors.
Keywords: Finite element, mandibular incisors retraction.

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INTRODUCTION

Orthodontic forces generate a set of mechanical stimuli triggering biologic reactions in associated periodontal ligament (PDL) and dento-alveolar bone, causing teeth to move to more appropriate positions in the jaw.[1] For this reason, the biomechanics of orthodontic tooth movement has been greatly investigated in the dental research community as part of a continuous effort to improve the clinical efficiency and outcomes of the treatment.[1,3] The finite element analysis method (FEM)has proven to be a benefitial technique for determining the stress and strain distribution of structures in dentistry since 1980.[4-10]

The present study aimed to determine stress and strain distribution on the four lower incisors under the effect of (400g) calculated retracted orthodontic force.

MATERIALS AND METHODS

The model of four lower incisors for finite element study is constructed to transfer experimental data of teeth and surrounding structures (periodontal ligament and bones) simulated as Typodont model of lower arch extracted class III Angle classification (Ormco, Japan) clinical case Figure (1).

Figure (1): Alignement and fixation of typodont model.

This model will be photographed on specific millimetric scale to transfer the data of teeth (metal teeth) embedded in wax to be processed for construction of finite element model analysis. Verifying the in vitro study of our real model (Typodont) which include the retraction of the four lower incisors via tooth movement with frictionless retraction mechanics on a Typodont model, the sample of the experiment consist of thirty retraction wires, ten rectangular preformed stainless steel rectangular 0.017X0.025 inch (0.43x0.64mm) retracting spring on continuous arch wire in the form of delta loop, ten looped Titanal (titanium arch wires) 0.017X0.025 inch (0.43x0.64mm) (without gable bend), and ten looped stainless steel wires 0.017X0.025 inch (0.43x0.64mm) (with 40° gable bends 20° alpha and 20° beta) (Lancer, USA), the frictionless retraction was accomplished consequently on preadjusted Roth twin stainless steel brackets of the lower four incisors teeth 0.022×0.030 inch (0.55x0.76mm) slot dimensions (Mini Lancer Bracket, USA), meanwhile, the canines and posterior teeth were gathered with the aid of hot cure acrylic bite plane (Major, Italy).Care is taken to transfer the data as accurate as possible with the aid of AutoCAD program to ensure standardization and accuracy of the model simulated in ANSYS finite element software. After verifying the model, several parameters were investigated including (labiolingual inclination change on level of crown, labiolingual inclination change on root level, mesiodistal inclination change,vertical position change, rate of space closure) using the verified finite element model to produce results for the investigated variables.

Finite Element Method

An accurate understanding of orthodontic tooth movement resulting from applied mechanics is necessary for elucidating the magnitude of optimum force and the type of system that should be used. The present work focuses on investigating the behavior of Typodont model using three dimensional finite element method, including the input of material properties for linear elastic analysis, as shown in Table(1).[11,12,13] Geometrical simulation processes of metal teeth, brackets, orthodontic wires and wax bar constructed with the aid of (AutoCAD 2010 software program, (Automatic Computer Aided Design), Autodesk, Autodesk, 3DMAX-8software program, Autodesk Inc. USA, Microsoft office programs (EXCEL 2007), ANSYS, software program, Version 10.8, 2009, Macrovision Europe, Ltd.), attributed for the verification and application of finite element model in studying several chosen parameters that affects the orthodontic movement.

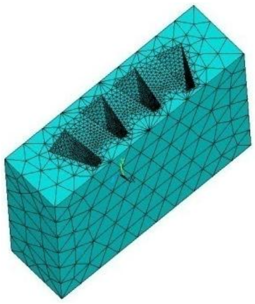
Table (1): Materials Properties Used in Finite Element Analysis

Material	Young Modulus E (N/mm^2)	Poisson's Coefficient
Paraffin wax	4200*	0.47
TIN & ANTIMONY alloy (tooth)	50000*	0.35
Stainless steel brackets	200000	0.3
Stainless steel wire	200000	0.3
NiTi wire	83000*	0.34*

*Craig, R.G, et.al., 1967; Proffit, W.R., et.al, 2007; Brady G.S., et.al.,2000; Soboyejo, W.O., Srivatsan, T.S., 2006.

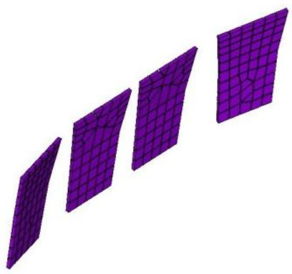
Modeling of Typodont's Components Geometry

The finite element software ANSYS is used in the present work to simulate the experimental work previously stated. The 8-node isoparametric brick Solid45 elements are used to simulate the teeth and wax base, as shown in Figure (2 a and b). The Shell63 elements are used to simulate the stainless steel brackets, as shown in Figure(2c).Three dimensional 2-node truss LINK8 elements are used to simulate the orthodontic wire, as shown in Figure (2 d).

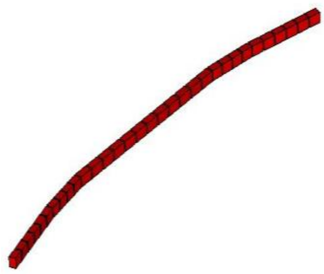


(a) 3D 8-node wax base brick element

(b) 3D 8-node teeth brick element



(c)Bracket 4-node shell element



(d) Wire 2nodelink element.

Figure (2): Brick elements simulation of wax base and teeth.

The photographic images of teeth are captured from three planes of space using digital camera, 8.1 Mega pixels (Sony Corporation, Japan). The camera is fixed to the wood bases at three positions to capture three measurements on the millimetric scale (two labiolingual inclination change) and (one mesiodistal inclination change).

Fixation of the camera is accomplished via screws penetrating the wood tables tightly fixing the camera in its place on the table to insure that no rotation will occur during photograph, standard distance about (10 cm) of the camera from the fixed Typodont articulator in three directions when camera is ON, the resulted image used to measure the boundary after making the required scaling processes using AutoCAD program. The boundaries of teeth are connected using 3D-MAX program to form three dimensional shape to simulate the teeth as accurate as possible. This process allows determining the coordinate of teeth boundaries and teeth size to draw it with an accuracy of (0.0001mm).

Mesh Generation of Finite element model

After completing the simulation of teeth geometry in three dimensions, the data is transferred to the finite element ANSYS software to create teeth volumes and specify the mesh properties and mesh size for each component of Typodont model.

The applicability of brick and tetrahedral Solid45 elements allows capturing the quadratic shape and the complex curved surfaces in the model. A convergence test of linear elastic analysis was carried out to understand the effect of various mesh densities on discretization approximation. A total of (52151) and (47395) 8-node isoparametric brick Solid45 elements are used to simulate the teeth and wax base respectively. The mesh size of the wax base is about (4mm) except at places near the teeth boundaries, the mesh there are refined to meet the size of (1mm) used for meshing the teeth. Total of (209) Shell63 elements are used to simulate the stainless steel brackets, whereas, mesh size is chosen to ensure the connection between teeth and brackets. Finally, (31) three dimensional 2-node truss LINK8 elements are used to simulate the orthodontic wires, and the mesh of these wire is chosen to comply with the size of mesh used for brackets along the line of wire actions. The final geometry and finite element discretization and boundary conditions of the assembled Typodont model is shown in Figure (3).

The bottom field extents of the wax base are assigned as fully fixed boundary conditions to prevent the nodes there from translations and rotations in three directions, as shown in Figure (3b). A full connection at common nodes between teeth and wax base and between teeth and brackets is assumed under orthodontic loading. Different types of connection between wires and brackets are tried to obtain the optimum result. A fully connection is used to simulate the connection between the orthodontic wire and bracket.

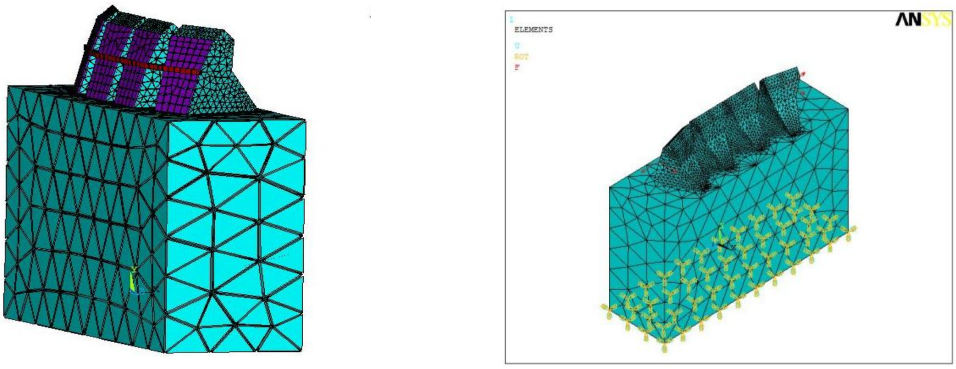


Figure (3): a)Finite element simulation of typodont model. b) Boundary conditions and applied loads of finite element.

The results of finite element simulation due to the applied loads are then reported for each model. The finite element analysis of the teeth model is carried-out replicates an orthodontic tipping system by applying concentrated forces directed along the wire section. Thus, two orthodontic forces, consists of three components of forces in x, y and z directions, are applied at the left and right lateral incisors, in the location of contact between orthodontic wire with brackets. The components of forces in x, y and z directions are estimated for each wire depending on the stiffness of each loop'[11] horizontal and vertical inclinations of the applied force angle,[14] and position of loops from lateral incisor. These forces are distributed effectively by the bracket and onto the crown of the teeth and the surrounding structures. A total force of 5N (500gm) is applied along the orthodontic wire. The force is applied gradually using 5 steps (five increments) each equal to1N (100gm) and the results are then reported for each step. The orthodontic arc wires are represented by 2-node three dimensional truss elements namely LINK8. Each wire bar is simulated explicitly by a three dimensional space truss element connected with the brick elements via stainless steel brackets at the nodes. Three translational degrees of freedom are allowed at each node, and different methods of bonding between wires and brackets can be used namely perfect bonding and coupling of nodes, as shown in Figure (4) having the same coordinates.(15)

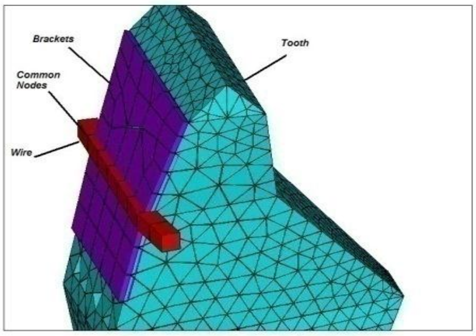


Figure (4): Wire element representation and bonding with brackets and tooth.

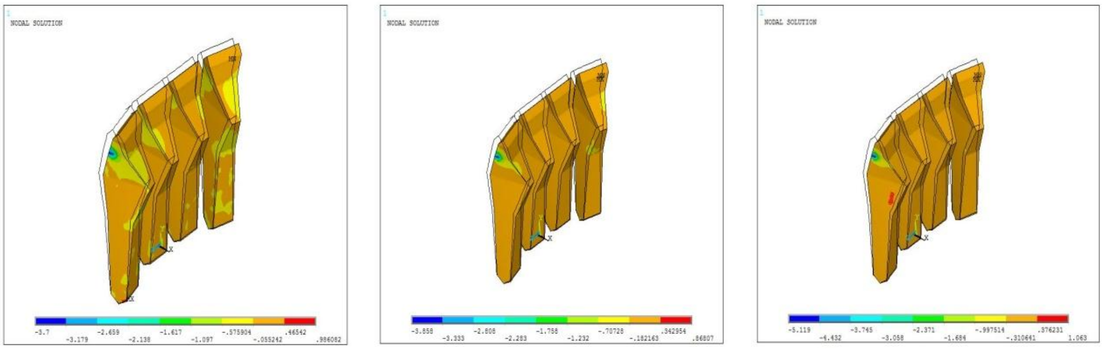
RESULTS AND DISCUSSION

Stress Distribution

The stresses distribution, at load of 400gm, from the models used in finite element verification in labiolingual direction (x-direction), mesiodistal direction (z-direction) and vertical direction (apical or occlussal) (y-direction) are shown in Figures (5, 6 and 7) respectively. Figure (5) shows that, a high compressive stress concentration in labiolingual direction are observed near the point offorce application and along the line of action of orthodontic wire at the crown of both lateral and central incisors, these values are (3.7, 3.9 and 5.1 MPa) for NiTi wire, Stainless steel wire and Stainless steel Gable wire models respectively. High tensile stress values in labiolingual direction are observed at the apex of roots of both lateral and central incisors which are (0.99, 0.87 and 1.06 MPa) for NiTi wire, Stainless steel wire, Stainless steel Gable wire models respectively.

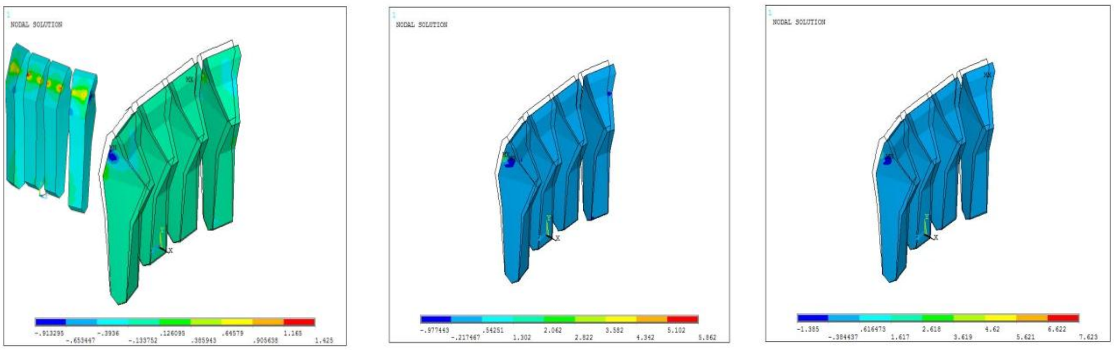
According to the present study, high compressive stress values in labiolingual direction are observed near the point of force application and along the line of action of orthodontic wire at the crown of both lateral and central incisors, in addition to that, the stress distribution are not the same for lateral and central incisors.It is clearly varied, especially in the mesiolingual and vertical directions. These findings conclusively agree with Murphy *et al*.,(16) who measured the retraction force delivered to the incisors and he found that Lateral incisors were affected by greater amount of retraction force than the central incisors.

Also the present results obviously agree with Reimann*et al*.,(17) and his conclusion which stated that the four anterior teeth seem to move almost independently,when calculating the displacements of the four anterior teeth as a result of the applied force couples. High compressive stress taken place in mesiodistal direction are observed near the point of force application and at the opposite corner of the crown of lateral incisor (mesiolabial angle of lateral incisor), these values are (0.91, 0.98 and 1.39 MPa) for NiTi wire, Stainless steel wire, Stainless steel Gable wire, models respectively.



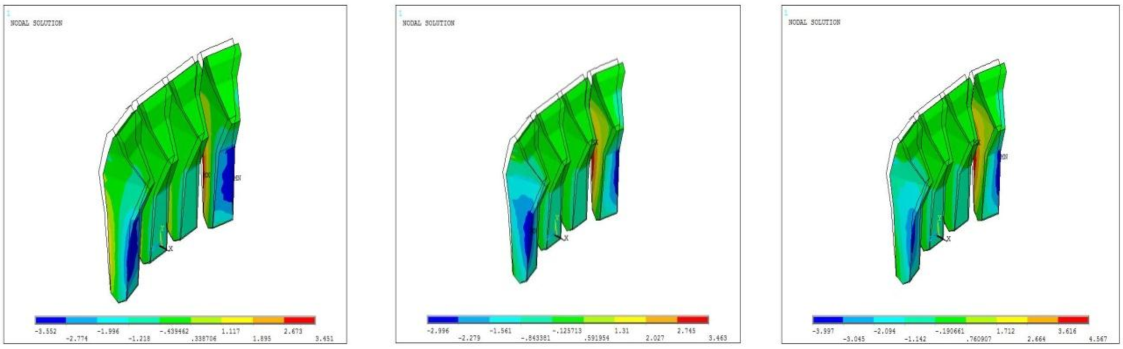
NiTiwiresStainless steel wire Gable wire

Figure (5): Stress distribution in labiolingual direction (x-direction).



NiTiwiresStainless steel wire Gable wires

Figure (6): Stress distribution in mesiodistal direction (z-direction).



NiTiwiresStainless steel wires Gable wires

Figure (7): Stress distribution in vertical direction (y-direction).

High tensile stress values in mesiodistal direction are observed at the line of action of orthodontic wire at the crown of both lateral and central incisors, these values are (1.4, 5.9 and 7.6 MPa) for NiTi wire, stainless steel wire, stainless steel gable wire models respectively. It can also be seen that the line of wire action (point of force application) along the crown of the four teeth suffer from stress concentration in both lingual and mesio-distal directions. This agrees with Tanne*et* *al*., Rudolph *et al*., Shaw *et al*., and Field,[3, 18-20] who found that disto-cervical region of the root experiences the greatest stress, corresponding to the orthodontic force application area. High tensile stress values in vertical direction are observed at the outer faces (labial aspect) and inner corners (mesiolabial corner) of roots of lateral incisors and high compressive stress values in vertical direction are observed at the inner faces (lingual aspect) and outer corners (distolingual corner) of roots of lateral incisors for NiTi wire, Steel wire, Steel Gable wire models respectively. This agree with study of compression and tensile stress of Field.[3]

High compressive stress values in vertical direction are observed at the inner faces (lingual aspect) and outer corners (distolingual corner) of roots of lateral incisors. These values are (3.55, 2.99, and 3.99 MPa) for NiTi wire, Stainless steel wire, Stainless steel Gable wire models respectively. High tensile stress values in vertical direction are also observed at the outer faces (labial aspect) and inner corners (mesiolabial corner) of roots of lateral incisors. These values are (3.45, 3.46, and 5.57 MPa) for NiTi wire, stainless steel wire, stainless steel gable wire models respectively.

CONCLUSIONS

The stress distribution is not the same for the all retracted segment and there was independent movement of lateral incisors from the central incisors except for the retraction using NiTi wires which exhibits uniform movements for both lateral and central incisor.

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