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A THREE DIMENSIONAL STRESS ANALYSIS INDUCED BY THE ISOGLIDE SPRING IN TRACTION OF PALATALY IMPACTED CANINE {FINITE ELEMENT MODELING STUDY}

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Abstract

Objective

This study aims to evaluate the stress distribution and displacement that result from the use of the isoglide eruption spring during palataly impacted canine traction using three-dimensional finite element analysis.

***Materials and methods**: A three-dimensional finite element model of the maxilla was developed from a scanned dry model of skull (meditT510). Traction was simulated*

With the isoglide eruption spring which is made of nickel titanium (1.2 N). Von Mises stress distributions and initial displacements of the palataly impacted canine and adjacent teeth were analyzed.

Results**: The isoglide spring showed* ***0.293MPa *stresses on the palataly impacted canine. The stress distribution decreased as the distance from the impacted canine increased. The stresses were* ***(0.225MPa)*** *on the adjacent lateral incisor and* ***(0.002MPa)*** *on the first premolar. The isoglide spring showed a total displacement of* ***(0.0002 mm)*** *on the impacted canine.*

***Conclusion**: The iso glide eruption spring is efficient in traction of palatally impacted canines with the stresses on the neighboring teeth decreased as the distance from the impacted canine increased* **.**

Keywords— •*impacted canine* • *isoglide eruption spring* • *impacted canine traction* •

Introduction

Dental impaction is a condition in which tooth cannot erupt because it may be retained by either adjacent bone or tooth . Following the third molars, upper canines are among the most frequently impacted teeth, with prevalence ranging from 1% to 3% . Therefore, impacted canines are defined as being those teeth not erupted within 6 months of their complete root formation or when they are not present in the arch during the eruption phase(1). Impacted upper canines are found in approximately 2 % of the general population, occurring more than twice as frequently in women (1.17%) as in men (0.51%) (2,3) . Palatal displacement of the maxillary canine is certainly more common than labial displacement, but the reported ratios for palatal vs labial canine impaction vary from 2:1 to 9:1 (4) . The palatal impaction of upper canines may result from an excess of space, rather than lack of space, which is frequently the cause of buccal impaction . Trauma is another possible cause of canine impactions and, certainly a genetic component also can play a role in the etiology(5). Two major theories associated with palatally displaced maxillary canines are the guidance theory and genetic theory(6). The guidance theory proposes that the canine erupts along the root of the lateral incisor, which serves as a guide, and if the root of the lateral incisor is absent or malformed, the canine will not erupt(7). The genetic theory points to genetic factors as a primary origin of

palatally displaced maxillary canines and

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includes other possibly associated dental anomalies, such as missing or small lateral incisors(8). Palatally impacted maxillary canines are genetically reciprocally associated with anomalies such as enamel hypoplasia, infraocclusion of primary molars, aplasia of second premolars, and small maxillary lateral incisors (9) . Among the local etiological factors, the ectopic position of the dental germ could be taken as the most important one; besides arch length discrepancies caused by lack of space; and the absence of an eruption guide, which is very common in cases of lateral incisor agenesis(10) However, the problem also seems to be associated with the long path that the canine
germs have to overcome until its final eruption site(11). Timely removal of the deciduous canine in 10 or 11 year-old children can sometimes prevents this problem from developing, but often surgical intervention may be required to retrieve over-retained canine teeth and prevent them from damaging neighbouring teeth(12). For a correct diagnosis and development of the treatment plan, it is essential to define the tooth location. Thus, it is essential to perform a detailed clinical examination, associated with radiographic and/or computed tomography(13). Clinical signs observed in cases of impaction are prolonged retention of deciduous canine, delayed eruption of the permanent canine and, depending on the position of the canine included, absence of vestibular bulging, presence of palatal bulging, and distal slope of the maxillary lateral incisor crown and may present, or not, midline deviation(13). The orthodontic treatment should be started as soon as possible to avoid secondary problems(14) . One of the most suitable procedures is orthodontic traction, and its success is directly linked to the management of side effects. Therefore, biomechanical knowledge is required to choose an ideal system of forces for each intended movement(15). The most common methods used to bring palatally impacted canines into occlusion are surgically exposing the teeth and allowing them to erupt naturally during early or late mixed dentition and surgically exposing the teeth and placing a bonded attachment to and using orthodontic forces to move the tooth(16) . The most common traction method for palatally impacted canines involves a surgical exposure followed by the bonding of the orthodontic attachment, so that a light and slow force can be applied to move the tooth along the correct position(16). Among these methods, the iso glide eruption spring that was used in this study. Ideal alignment of the impacted canine teeth with a successful orthodontic treatment is dependent on the surgical procedure, individual variations, and determining the exact position of the impacted tooth and also its relationship with neighboring teeth. Biomechanical properties such as the amount of force, the application point and direction of the force are highly important to achieve desired functional and aesthetic outcomes(17,18). In traction of a palatally impacted canine, several mechanics such as Kilroy spring, elastic chain, gold chain, Nickel-Titanium (NiTi) closed-coil spring, Transpalatal (TPA) arch with stainless steel (SS) auxiliary, Titanium molybdenum alloy fishing rod, removable appliances, magnets, mini implants and Piggyback wires are being used(19,20). These mechanics are expected to create an optimal biological response by applying the optimal force and inducing the minimum tissue damage. It is highly important in terms of ideal tooth movement that the force is continuous and constant. The isoglide

eruption spring is a mechanic that is attached over the archwire in the region of the impacted tooth and applies continuous force. It is used for traction of palatally or buccally impacted canine by applying vertical and lateral forces. The finite element method (FEM) is an engineering resource applied to calculate the stress and deformation of complex structures, and has been widely used in orthodontic research. With the advantage of being a non-invasive and accurate method that provides quantitative and detailed data on the physiological reactions possible to occur in tissues, applying the FEM can anticipate the visualization of these tissue responses through the observation of areas of stress created from applied orthodontic mechanics(21).

Material and methods

This study was approved by The Ethics Committee of Faculty of Dentistry, Minia University, The current finite element analysis designed in this, simulating a clinical situation , a palataly impacted canine that has to be tracted by using isoglide eruption spring .

Construction of the finite element (FE) model:

.**1. Getting the geometrical outline**

An Identica hybrid3D dental laser scanner(MEDIT T510) was used to scan the desired structures of craniomaxillary complex (maxilla) producing an STL file . The analytical model was selected that has no developmental abnormalities or gross defect. the scanned images was converted to a solid work model by the Solidworks software program2020.

2. Model components 3D drawing.

At the first stage, the teeth, cortical and spongious bones were automatically segmented based on their own Hounsfield units. After manual reconstruction of missing regions, 3-dimensional (3D) digital model of maxillary dentition was obtained(HIGHEND3D) applying the natural diemensions of the maxillary teeth on it(22) . The 3D finite element model including maxillary dentition with the corresponding periodontal ligament (PDL) and alveolar bone was constructed by soildworks2020 (spO.O) software,The teeth, alveolar bone, and periodontal ligament (PDL) were viewed as homogenous and isotropic. The PDL was modelled with an average of 0.2 mm linear thickness(23), and was embedded in the alveolar bone and the root surface ,The impacted canine crown was cleared from any bony contact to allow for accurate simulation the role of the PDL in a response to the force. The mucosa was drawn with an average of 2 mm linear thickness (24).

3. Appliance design:

0.022-inch slot brackets, molar tubes with 0.022 × 0.028 inch in dimension, and 0.016× 0.022 inch SS rectangular wire were placed. The brackets were positioned on the buccal surfaces of the all teeth so that the middle point of the bracket base would correspond to the middle of the crown and the whole maxillary dentition except impacted canine were rigidly fixed to the archwire. The isoglide eruption spring was manually constructed from NiTi with dimensions (length 7.7mm ,wire cross section .2mm),the amount of exerted force (1.2N), The constructed components were assembled together to form the model with the isoglide spring . The technique of model assembly was done by the mating function of the assembly mode in solid work program software.

4. **Material characteristics** :

All materials in the study were considered to be homogenous, isotropic and linearly elastic (properties equal in three dimension).The modulus of elasticity and Poisson"s ratio for the different component materials used in the study were listed in the(table 1) .

5- **Defining contacts and gaps between components**;

In this study, bonded contact was defined for every two contacts which means that these objects were displaced as one unit upon load application and that the two contact bodies can´t be separated or penetrated.

6-**Defining model fixture and restrain for each model**;

All the elements were allowed to translate in all direction except rotation .The only restraint applied was a fixed restrain on the back and top of the maxilla. No translation was allowed for these surface in all directions .(Fig 1)

7- **Defining load applied for each model;**

1.2 N forces were loaded in the setup (25) due to the different physical and biomechanical properties . The force vector was applied in the same direction from the button attached to the crown of the impacted canine to the middle of the space reserved for the impacted canine alignment. After force loading, the average von Mises stresses and the 3D initial teeth displacements data were collected. Von Mises stress is a metric measurement to determine the point that the elasticity limit is exceeded and permanent deformation results. The initial displacements were collected from node sets containing from the crown of the each tooth .(Fig 2)

8- meshing ;

A high quality solid mesh was used in this study to create 3D parabolic tetrahedral solid elements. As a solid mesh was used the resultant nodes were allowed to translate along any of the three orthogonal directions unless a restraint was applied, but no rotation was allowed,with crvature based mesh and Minimum element size 4.30 mm .(Fig 3)

9-Analysis;

The analysis was run by the Fast Finite Element Solver (FFE plus) which is an alternative method via solidworks 2020 sp0.0 .

A linear static test was done and data were collected, the results will be presented as Von Misses stress, at the time of force application (**1st capture**) and calculated at the elements in Mega Pascal (**Mpa**) & displacement which present in(**mm**).

Results

Displacement ;

Teeth nodal displacements were evaluated in the resultant of (x, y and z) axes .The maximum total intial displacement with the palataly impacted canine was seen with the isoglide spring was (0.0002mm). subjecting to the displacement of the adjacent teeth ,

The displacement values created by the isoglide spring for lateral incisor (0.0006mm) (Fig 5), first premolar (0.0004) and arch wire at position of canine alignment (0.0006mm) .

Stress Distribution ;

Stresses on the impacted canine were within the yield properties of it , the von misses stresses recorded on the impacted canine were 0.293MPa. The traction force applied resulted in the 0.225MPa and 0.002MPa stresses on the lateral incisor and the first premolar respectively.

The corresponding stresses gradually decreased in the mesial direction from the lateral incisor towards the contralateral second molar and distally from the first premolar.

Discussion

Among mechanics used in traction of palataly impacted canine is the isoglide eruption spring that is included in this study . To avoid complications that occurred during traction as root resorption , prolonged treatment time and undesirable teeth movement of the adjacents, we must to know the proper magnitude , direction of the applied force and the amount of stresses in response , in adittion; poorly controlled orthodontic extrusion may lead to undesired stresses on the impacted tooth ,adjacent teeth and surrounding tissues. Therefore this study is done to determine amount of stress distribution and intial displacements of the impacted canine and adjacent teeth during traction of the palataly impacted canine, providing clinicians with informations that help them during planning the impacted canine traction treatment, accordingly the FEM results , it was demonstrated that this mechanic deliver high stresses on the impacted canine ,

The stress distribution and displacement responses of the impacted canine and adjacent teeth might result from the force pattern of the used mechanics where the isoglide spring produce slow continous force , also the force magnitude and the physical and biomechanical characteristics of the materials in the mechanics.

stresses varied with force directions(26) which is very important factor in selection of the traction system since impacted canine moves in accordance to the traction system . Higher stresses were translated on the impacted canine and adjacent teeth as the applied force in the study are considerd a direct buccal force (vector from canine to the point on the wire) , which is similar to Zeno et al(27) who stated that the application of a buccal force caused more stresses on the palatally impacted canine and adjacent teeth.

In this study according to colour map for stress distribution on the impacted canine, the majority of stresses concentrated at the crown of the impacted canine and cervical region of the root, decreased progressively toward the apex(Fig 4). This point is the only one that make us preferring the direct buccal force than distal and vertical forces during traction where stresses are concentrated at the root apex increasing possibility of root resorption, which is consistent with another Study**(26)** which found that distal and buccal forces resulted with a greater stress than vertical forces at the apical third of the canine root and the higher stresses generated by the buccal force at the cervical level.

Also according to this study it was noticeable that stress distribution on the remaining teeth engaged on the archwire decreased progressively as the distance between the force application points and the related tooth increased in both mechanics which is consistent with zeno et al(27).

This study provided evaluation for the amount of intial displacements. The application of the isoglide spring yielded displacement of the impacted canine and the adjacent teeth, which decreased distally from first premolar and mesially from lateral incisor.

The amount of intial displacements might be related to the magnitude of the applied forces . The optimal force is required to achieve the maximum tooth movement with minimum negative side effects. Bishara et al **(28)** it recommended to use light forces by maximum 60g during traction of impacted canine . Many studies mentioned that pressures higher than the human systolic pressure which is 16 KPa may lead to tissue necrosis and hyanlinization of periodontal ligaments , which is the key of the tooth movement**(29).**

Conclusions

1- Main stresses on the impacted canine are concentrated at the crown and cervical region of the root during the traction using the isoglide eruption spring .

2- The stress distribution decreased in the mesial direction from the lateral incisor towards the contralateral second molar and distally from the first premolar toward the second molar .

Table 1 Material property data and their Poisson's ratio

Material	Modulus of elasticity (Mpa)	Poisson's ratio
cortical bone	13700	0.3
Cancellous bone	79000	0.35
Stainless steel	16000	0.3
Nickel titanium	75000	0.3
Periodontal Ligament	1.18	0.45
Teeth	22000	0.37

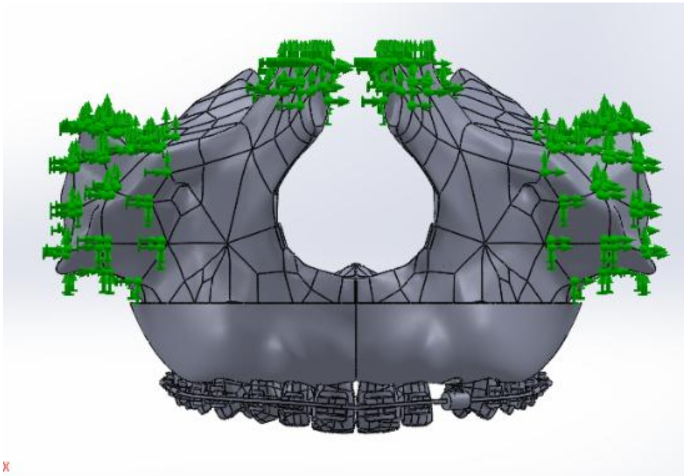

Fig . 1 Fixture and restrain of the model

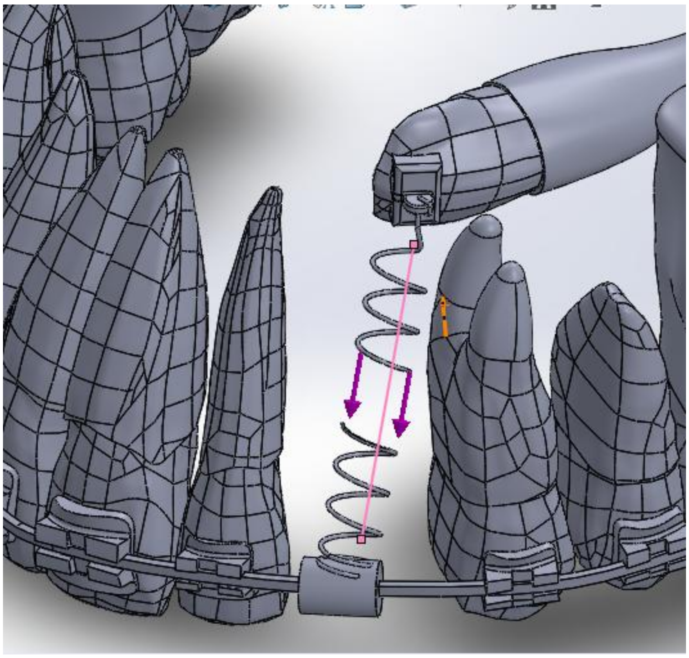

Fig . 2 defining load applied on the spring

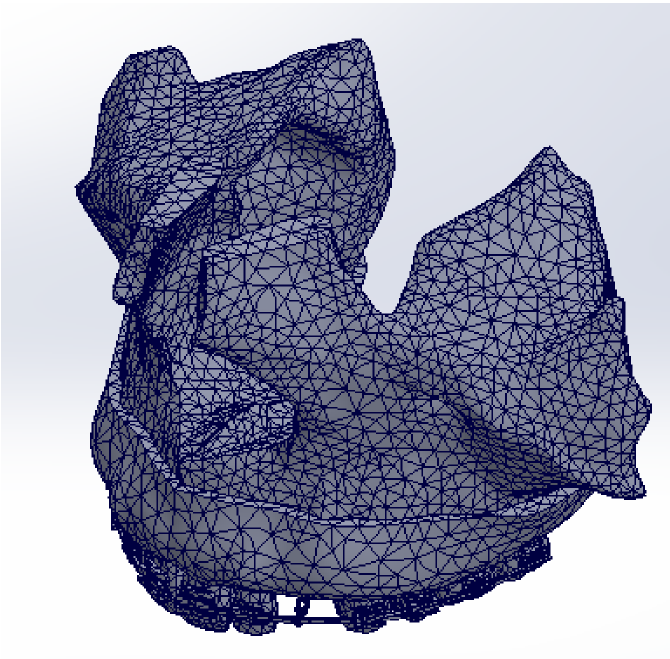

Fig .3 meshing model

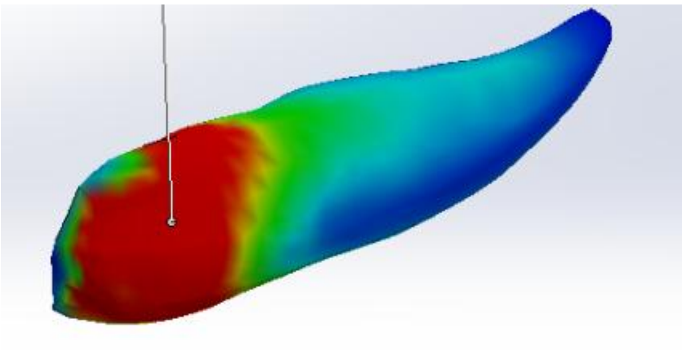

Fig .4 stress distribution on caine spring model

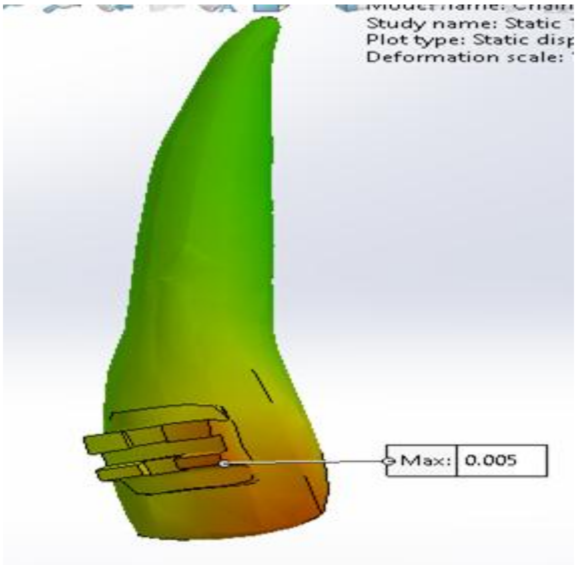

Fig.5 displacement of lateral incisor chain model

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