ISSN 1392 - 1207. MECHANIKA. 2003. Nr3(41)

Finite Element Investigations on Biomechanics of Lower Canine under the Influence of an Orthodontic Force

J. Danielytė*, R. Barauskas, R. Gaidys***, A. Gaidytė******

**Kaunas University of Technology, A. Mickevičiaus 37, Kaunas, LT-3000, Lithuania, E-mail: Jovita.Danielyte@ktu.lt*
***Kaunas University of Technology, Studentų 50, Kaunas, LT-3000, Lithuania, E-mail: Rimantas.Barauskas@ktu.lt*
****Kaunas University of Technology, Studentų 50, Kaunas, LT-3000, Lithuania, E-mail: Rimvydas.Gaidys@ktu.lt*
*****Kaunas University of Medicine, Lukšos-Daumanto 6, Kaunas, LT-3000, Lithuania*

1. Introduction

Tooth movement during orthodontic treatment starts as a certain level of mechanical load is exceeded. The path of the tooth movement depends on the force – moment ratio created by orthodontic device at the center of resistance. In order to achieve a predictable and physiologically allowable orthodontic tooth movement the center of resistance (C_{RES}) of the tooth should be identified.

It is generally accepted that stresses induced in the periodontal ligament (PDL) by the orthodontic force system may initiate the bone remodeling process. Stress profiles necessary for physiological teeth movements are determined to be about 2000-2600 Pa. Maximum stress level and it's location should be revealed by investigating the stress distribution in the PDL.

The aim of this study is: to identify biomechanical characteristics of the lower canine as locations of centers of resistance (C_{RES}) and rotation (C_{ROT}) and to investigate the stress distribution in periodontal ligament of the lower canine at forcing modes and levels able to initiate various types of tooth movement, by performing the finite element modeling in 3D.

2. Finite Element Model of the Tooth

The 3D model of the lower canine, the PDL, and alveolar bone has been developed and used throughout the research.

The geometric model of the tooth and it's supporting structures were based on the tomographic X - ray cross - section images analysis [1]. After X - ray images were scanned, by means of a specially written program, data points were marked on tooth's boundaries on the X - rays image cross - section and connected together by using the cubic spline interpoliation. In this way the outline of the section of the tooth was obtained (Fig. 1). In analogous manner other sections of the tooth were treated. Consecutive curves have been joined in order to form the tooth volume geometry.

Boundaries of PDL and the alveolar bone could be easily detected from the same X - ray tomography cross - section images. The created 3D FE models of the tooth, the periodontium and the alveolar bone are shown in Fig. 2 [2, 3].

The 4 node tetrahedral finite element SOLID72 with 6 nodal degrees of freedom was selected for modeling such irregularly shaped bodies as human teeth. Finally, the finite element model of the lower canine and it's supporting structures consisted of 12000 nodes and 68000 elements (Fig. 3).

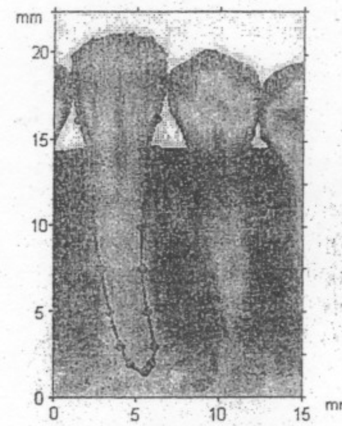


Fig. 1 Tomographic X - ray cross - section image of the lower canine and tooth contour curve

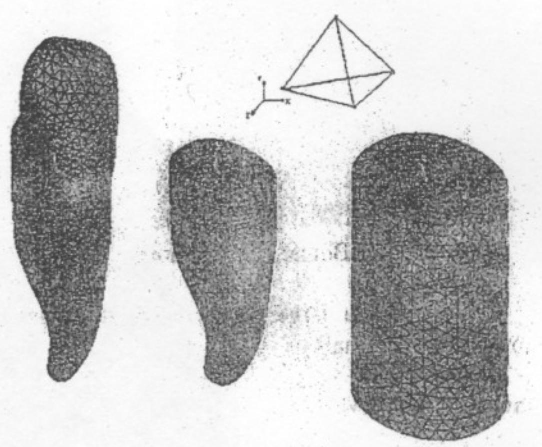


Fig. 2 FE model of the tooth, periodontal ligament and alveolar bone

Fig. 3 *FE* model of the lower canine

The tooth, periodontal ligament and alveolar bone have been assumed to be homogenous and isotropic elastic structures (Table 1) [4].

Table 1

Material properties

Material	Young's modulus E, Pa	Poisson's ratio ν
Tooth	$2 \cdot 10^{10}$	0.15
Periodontal ligament	$1.8 \cdot 10^{6}$	0.49
Alveolar bone	$1.4 \cdot 10^{10}$	0.15

In order to find the location of the C_{RES} [5-9] and to calculate stress distribution in the PDL [10-12] all degrees of freedom were restricted at the base of the alveolar bone model. The mechanical load imitating the orthodontic force was applied to the buccal surface of the model (Fig. 4).

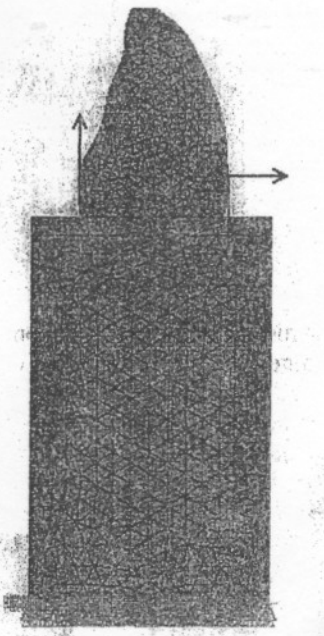


Fig. 4 Boundary conditions

The nonlinear large displacement static analysis was done with FEM analysis system ANSYS 6.0.

3. Control of Tooth Movement

Type of tooth movement depends on the amount and direction of forces acting in the C_{RES}. C_{RES} is the point where the resistance to the body's movement is concentrated. The center of resistance of a free tooth is situated at the center of mass. In a restrained tooth the position of the center of resistance depends upon the boundary conditions [13]. C_{RES} of the lower canine is located at the upper third of the root length apical to the alveolar crest [9].

In orthodontics it is impossible to apply force directly to the root of the tooth. The orthodontic forces are applied at the bracket on the crown of a tooth. The acting force produces the tooth movement, the couple and the counterbalancing moment necessary to control the position of tooth's position. The moment/force (*M/F*) ratio of the applied force and moments determine the type of the movement and the C_{ROT} (Fig. 5) [6, 9].

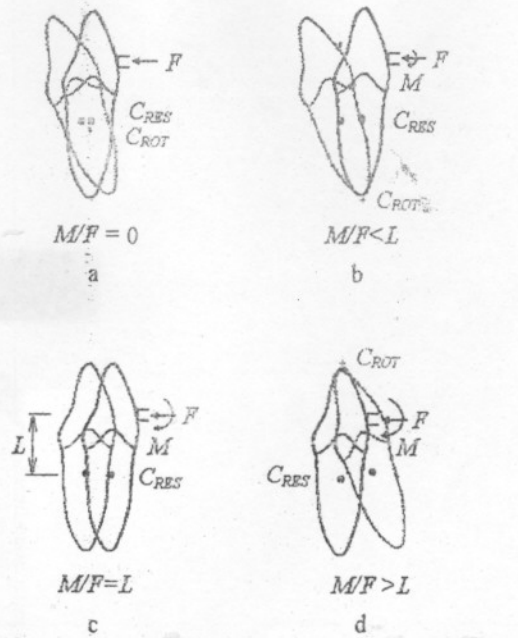


Fig. 5 Types of tooth movement: a - uncontrolled tipping; b - controlled tipping; c - translation; d - torque

The action of a single force with no moment applied produced the uncontrolled tipping with the C_{ROT} positioned in the middle of the root of the tooth (*M/F* ratio was 0/1). As the *M/F* ratio increases (*M/F* ratio was 5/1), the position of C_{ROT} is displaced from the C_{RES} and a controlled tooth movement is achieved. When *M/F* ratio becomes equal to the distance between the C_{RES} and force action position, the C_{ROT} approaches infinity, and the tooth undergoes the pure translation (*M/F* ratio was 10/1). If *M/F* ratio exceeds this distance, the tooth's root movement is presented. The root movement is used to describe the situation in witch only the root moves, with no appreciable crown movement. Such movement is named torque (*M/F* ratio was 12/1).

Our study is based on the assumption that the C_{RES} coincides with C_{ROT} during the uncontrolled orthodontic tooth tipping. The tooth is loaded by two moments of force: the first one tends to rotate the tooth around the vertical axis, and another tends to tip it to the lingual side (Fig. 6, a). We found that the distance between C_{RES} and tooth root apex is 8.93 mm. The C_{RES} is determined to be at 58 % of the distance from the root apex (Fig. 6, b).

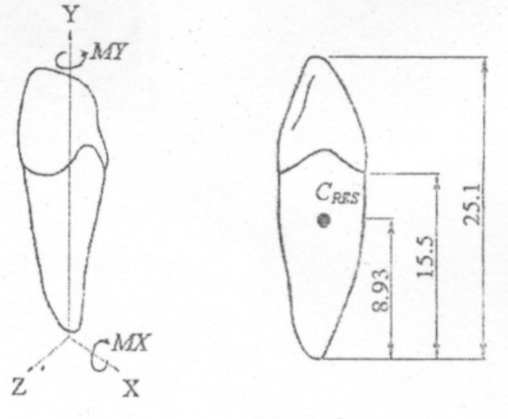


Fig. 6 Center of resistance of the lower canine: a - scheme of identification; b - location

Our results are close to those obtained by C.J. Burstone [9] stating that C_{RES} is at 66% of the tooth height from the apex and by R. Nanda [8] where 70% has been mentioned.

The correctness of the determined position of the C_{RES} can be verified by applying the force at its position. Under such an action, the tooth performs pure displacement in the direction of the force (Fig. 7) [9].

The type of tooth movement is defined by M/F ratio at the bracket. Fig. 8 illustrates the relationship of displacements of the lower canine against the M/F ratio.

Fig. 7 The tooth performs pure translation, if the line of action of a force passes through the C_{RES}

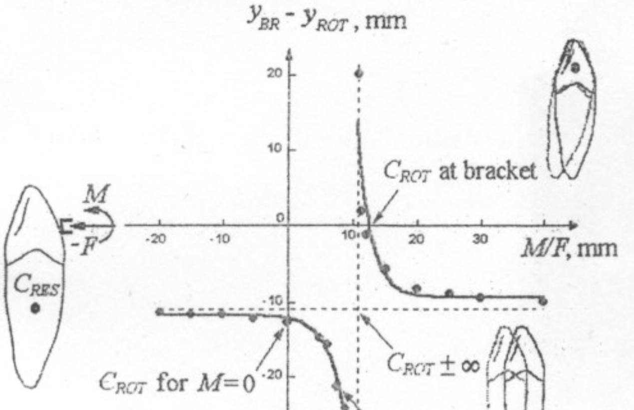


Fig. 8 Relationship of movements of the lower canine against the M/F ratio

The calculated values of M/F ratio in our study show that the canine undergoes translation if M/F = 10.7 mm. The controlled tipping will be produced if M/F = 7.8 mm, and tooth root will be torque, if M/F = 12.1 mm.

4. Investigation of Stress Distribution in PDL

The optimal orthodontic force used for creating the movement of the tooth may be defined by maximum limit of stress that capillary blood vessels in the periodontal ligament are able to withstand. The optimal orthodontic force varies with the location of axis of rotation.

The stress distribution in the PDL was investigated loading the tooth at the bracket in 4 different ways (Table 2). In all cases the tooth was loaded by the same force of 0.1 N, and 4 different moments: 0 N·mm; 0.78 N·mm; 1.07 N·mm; 1.21 N·mm correspond to each of the 4 cases.

Table 2

Types of loads

Type of movement	M/F ratio, mm
Uncontrolled tipping	0
Controlled tipping	7.8
Translation	10.7
Torque	12.1

In the first case the stress distribution in the PDL has been investigated during uncontrolled tipping, i.e. when the tooth is rotating about C_{ROT} located in the middle of the root (M/F = 0 mm). Two zones of tensile and two zones of compressive stress are produced in the PDL in this case (Fig. 9).

The zone of tensile stress is located in the buccal surface beyond the C_{ROT} and the compressive stress zone is located in the lingual surface below the C_{ROT}. The stress produced by such loading reaches about 6000 Pa at the crest of the alveolar bone and exceeds the physiologically admissible stress limits (2000 Pa). The same happens with stress in the apex area (about 3000 Pa). It means that the investigated forces acting at the buccal surface of the tooth are too big.

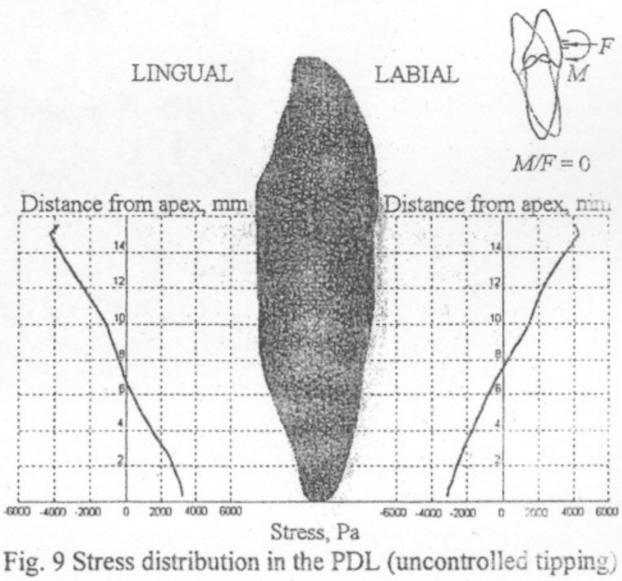


Fig. 9 Stress distribution in the PDL (uncontrolled tipping)

During the controlled tooth movement (controlled tipping at M/F = 7.8 mm) tensile stress is formed in the PDL area at the buccal side and compressive stress – at the lingual side (Fig. 10). The admissible stress limits in the tensile and compressive zones are not exceeded in this case.

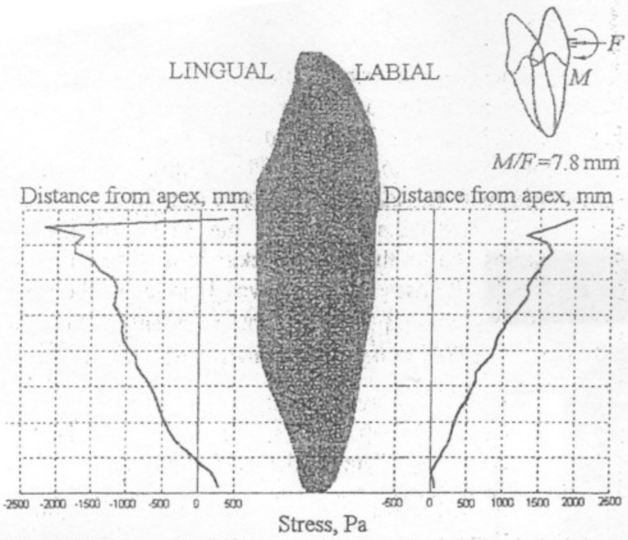


Fig. 10 Stress distribution in the PDL (controlled tipping)

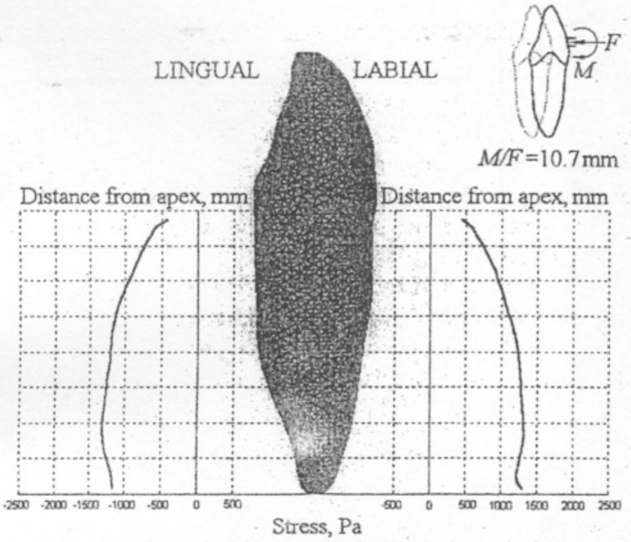
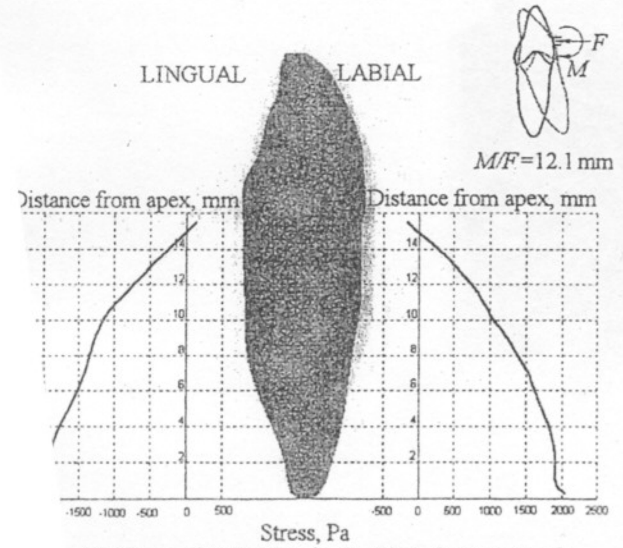


Fig. 11 Stress distribution in the PDL (translation)



. 12 Stress distribution in the PDL (root torque)

In the case of translation of the tooth 0.7 mm) the stress in the PDL varies between 500 Pa (Fig. 11). Allowed stress limits are not ex- this case, too. The tensile zone is formed on the rface, and the compressive one on the opposite side.

Fig. 12 illustrates the zones of tension an pression during rotation of the root. In this case the does not exceed 2000 Pa and is within the allowable The tensile area is formed on the loaded surface, a compressive zone on the opposite side.

5. Conclusions

The ability to know and to control couple - force ratios at the bracket can be regarded as a key to dictable and controlled teeth movements. The distribu of stress in the periodontal ligament during tooth mo ment was investigated in order to find optimal magnitud of orthodontic forces in various simulated conditions.

1. The geometric model of the tooth and it's su porting structures was based on the tomographic X - ra cross - section images analysis. This means that mode done in vivo.
2. The location of the center of resistance in the lower canine has been found to be located at 58 % of th root length measured from the root apex.
3. In order to produce the controlled tooth movement the *M/F* ratio values are: *M/F* = 10.7 mm fo translation, *M/F* = 7.8 mm for tipping and *M/F* = 12.1 mm for the tooth root torque.
4. Stress in the periodontal ligament increase up to 6000 Pa in tooth uncontrolled tipping.

References

1. **Lin, C.-L., Chang, C.-H., Cheng, C.-S., Wang, C.-H.** Automatic Finite Element Mesh Generation for Maxillary Second Premolar.-Computer Methods and Programs in Biomedicine, 1999, No59, p.187-195.
2. **Bourauel, Ch., Freudenreich, D., Vollmer, D., Kobe, D.** Simulation of Orthodontic Tooth Movements.-J. of Orofacial Orthopedics Fortschritte der Kieferorthopädie, 1999, No60(2), p.136-150.
3. **Geramy, A.** Alveolar Bone Resorption and the Center of Resistance Modification (3-D Analysis by Means of the Finite Element Method).-American J of Orthodontics and Dentofacial Orthopedics, 2000, No117(4) p.399-405.
4. **Middleton, J., Jones, M. L., Pande, G.N.** Computer Methods in Biomechanics & Biomedical Engineering –2.-Gordon & Breach Publishing Group, 1998. -312 p.
5. **Yoshida, N., Jost-Brinkmann, P.G.** Experimental Evaluation of Initial Tooth Displacement, Center of Resistance, and Center of Rotation under the Influence of an Orthodontic Force.-American J of Orthodontics and Dentofacial Orthopedics, 2001, No120(2), p.190-197.
6. **Raboud, D.W., Faulkner, M.G., Lipsett, A.W.** Three - Dimensional Effects in Retraction Appliance Design.-American J. of Orthodontics and Dentofacial Orthopedics, 1997, No112 (4), p.399-409.
7. **Choy, K., Pae, E.-K., Park, Y.** Effect of Root And Bone Morphology on the Stress Distribution in the Pe-rio-Dontal Ligament.-American J. of Orthodontics and Dentofacial Orthopedics, 2000, No117(1), p.98-105.
8. **Nanda, R.** Biomechanics in Clinical Orthodontics.-Philadelphia London: W.B. Saunders company, 199

-248p.

9. **Burstone, Ch.J.** Modern Edgewise Mechanics and Segmented Arch Technique.-Glendora,Ormco Corporation, 1995.-139p.
10. **Jeon, P.D., Turley, P.K., Ting, K.** Three - Dimensionnal Finite Element Analysis of Stress in the Periodontal Ligament of the Maxillary First Molar with Simulated Bone Loss.-American J. of Orthodontics and Dentofacial Orthopedics, 2001, No119(5), p.498-504.
11. **Vollmer, D., Bourauel, Ch., Maier, K.** Determination of the Centre of Resistance in an upper Human Canine and Idealized Tooth Model.-European J. of Orthodontics, 1999, No21, p.633-648.
12. **Haihong, Q., Chen, J., Katona, T. R.** The Influence of PDL Principal Fibers in a 3-Dimensional Analysis of Orthodontic Tooth Movement.-American J. of Orthodontics and Dentofacial Orthopedics, 2001, No120(3), p.272-279.
13. **Smith, R.J., Burstone, Ch.J.** Mechanics of Tooth Movement.-American J. of Orthodontics and Dentofacial Orthopedics, 1984, No85(4), p.294-307.

J. Danielytė, R. Barauskas, R. Gaidys, A. Gaidytė

APATINIO ILTINIO DANTIES, VEIKIAMO ORTODONTINIŲ JĖGŲ, BIOMECHANIKOS TYRIMAS, NAUDOJANT BAIGTINIŲ ELEMENTŲ MODELIUS

R e z i u m ė

Ortodontinio gydymo sėkmę lemia teisinga ortodontinių biomechaninių jėgų sistema bei dėl jos veikimo atsiradusių įtempių pasiskirstymas periodonte. Danties judėjimo pobūdį lemia momento ir jėgos santykis, esantis danties pasipriešinimo centre. Todėl, norint parinkti tinkamą ortodontinių jėgų sistemą ir valdyti danties judėjimą bei nustatyti įtempius periodonte, reikia sudaryti danties ir jo aplinkos audinių baigtinių elementų modelius. Šiame darbe, naudojant erdvinį baigtinių elementų modelį, nustatyta apatinio žandikaulio iltinio danties pasipriešinimo centro padėtis. Ištirta momento ir jėgos santykio įtaka danties atliekamam judesiui. Apskaičiuoti įtempiai danties periodonte, esant įvairiems danties judesiams. Danties ir jo aplinkos modeliai sudaryti ir skaičiavimai atlikti naudojant baigtinių elementų analizės sistemą ANSYS 6.0.

J. Danielytė, R. Barauskas, R. Gaidys, A. Gaidytė

FINITE ELEMENT INVESTIGATIONS ON BIOMECHANICS OF LOWER CANINE UNDER THE INFLUENCE OF AN ORTHODONTIC FORCE

S u m m a r y

The success of the orthodontic treatment mostly depends on the correctly chosen orthodontic forces and tensile - compressive stress distributions in the periodontal ligament. The moment/force ratio at the center of resistance determines the type of tooth movement. The finite element model of the tooth and it's supporting structures was created, to study types of tooth movement and corresponding stress in periodontal ligament, under orthodontic force action. Location of the center of resistance of lower canine was determined by using the 3D finite element model in ANSYS finite element software. The moment/force ratio influence on types of tooth's movement has been investigated. Stress distribution during different modes of the tooth movement were calculated.

Й. Данелите, Р. Бараускас, Р. Гайдис, А. Гайдите

АНАЛИЗ БИОМЕХАНИКИ НИЖНЕГО КЛЫКА ПОД ВОЗДЕЙСТВИЕМ ОРТОДОНТИЧЕСКИХ СИЛ ПРИ ПОМОЩИ МОДЕЛЕЙ КОНЕЧНЫХ ЭЛЕМЕНТОВ

Р е з ю м е

Успех ортодонтического лечения зависит от того, правильно ли подобрана система ортодонтических биомеханических сил и воздействия, вызванных ими напряжений в периодонте. Перемещения зуба определяет соотношение момента и силы, действующих в центре сопротивления зуба. Чтобы подобрать подходящую систему ортодонтических сил и контролировать перемещения зуба, а также определить напряжения в периодонте, нужно составить модель зуба. С помощью системы конечноэлементного анализа ANSYS 6.0 составлена конечноэлементная модель нижнего клыка и установлено место центра сопротивления. Определены перемещения зуба при разных соотношениях нагружающих момента и силы. Расчитаны напряжения в периодонте зуба.

Received February 27, 2003