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Use of 3D finite element models in study of normal and abnormal dental mobility as affected by a minimal decrease in alveolar bone height

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Abstract The study deals with dental mobility and dental root-side periodontal pressure for left-side mandibular teeth. Geometric models of the teeth were generated from patient V.’s computed tomographic data. Displacements and stresses in the tooth/periodontium system were determined using ANSYS-integrated three-dimensional finite elements method. Vertical and horizontal biting effects in case of normal and periodontitis-reduced alveolar bone height were reviewed. An almost two fold increase in dental mobility as compared to normal level was showed to cause contact stresses at the dental root-to-periodontium interface to be built up by only about 10% to 20%, thus indicating absence of periodontal overload. The paper shows an increase in periodontal load should be estimated from maximum displacements of periodontium-contacting part rather than the entire tooth. These displacements were increased by 20% to 40%, thus correlating with only small contact stress buildup.

1. Introduction

When periodontium is healthy, teeth are secured against negative effects of occlusal loads by support function of periodontal ligament and alveolar bone tissue which have unique capability of adapting to occlusal conditions which vary throughout a lifetime due to loss of some teeth, teeth replacement, orthodontic treatment, etc. [1, 2]. Furthermore, occasional small displacements of teeth resulting from occlusal load have a beneficial effect on periodontal tissue system [1, 2] being an integral part of periodontal trophism.

However, biting effects can shift from positive to negative, and result in periodontal overloading and formation of secondary hyperfunctional occlusion. It is mainly due to decrease in alveolar height which results from periodontal inflammation, and to loss of teeth which causes significant morphological and functional changes in dentition due to increased load on remaining teeth. Tooth overload results in occlusal injury which will build up as periodontal destruction becomes increasingly prevalent over regeneration. Increasing injury causes further alveolar atrophy, periodontal gap widening, periodontal destruction. This brings about further overload of remaining attachment, faster destruction and, finally loss of a tooth. In terms of mechanics, such process may be described as destabilization of dynamic dental balance.

Effects of occlusal load on periodontal tissue system and alveolar bone tissue both in good health and in progressive periodontitis have been studied for a long time in animal experiments [3-7], and in the
course of human clinical trials [8-11]. Computer models involving finite elements method (FEM) have lately been increasingly used to analyze effects of forces which act on teeth and periodontal tissues. Such studies deal with effects both of orthodontic forces [12-15] wherein alveolar absorption plays a beneficial role, and periodontitis-related biting forces [16-18] wherein absorption is extremely detrimental.

One milestone in elimination of secondary hyperfunctional occlusion and masticatory force redistribution is splintage which uses various techniques and structural designs. Splintage allows to control dental mobility, reduce considerably or eliminate periodontal overload, inhibit periodontal and alveolar destruction [2]. Any missing teeth are replaced on a reasonable basis [1,2], in order to redistribute some of occlusal load on dentition and basal seat tissues. A major goal of prosthodontic stage in periodontitis control is to improve periodontal haemodynamics by keeping dental mobility on a physiological level since a splint that impacts periodontal tissues too rigidly can bring about detrimental changes in the condition. Therefore, it is topical to delimit beneficial and harmful effects of biting force, in order to maintain natural dental mobility which ensures stable haemodynamics in the course of prosthodontic treatment. To this end, this study deals with dental mobility in patient V., in good health and in an early stage of periodontitis, using ANSYS-integrated FEM.

2. Materials and methods

Geometric models of left-side mandibular teeth (figure 1) and the average thickness of the periodontal ligament (PDL) (table 1) were obtained by processing data from patient V.’s cone-beam computerized tomogram. The findings were used to set (table 1): normal periodontal height as cervical line-to-dental apex distance, and incipient stage of periodontitis, as reduced alveolar height.

| Table 1. Normal and abnormal periodontal ligament sizes. |
|---|---|---|---|---|---|---|---|
| PDL thickness (mm) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Normal periodontal height (mm) | 0.240 | 0.246 | 0.250 | 0.248 | 0.248 | 0.250 | 0.250 |
| Reduced periodontal height (mm) | 8.55 | 10.32 | 10.47 | 8.73 | 8.89 | 13.25 | 10.15 |

In terms of mechanics, periodontal ligament can be described as a viscoelastic body [19, 20]. However, the periodontal lesions in question result from periodontitis-related occlusal load and are therefore long-term lesions. Thus, viscosity effects may be ignored and periodontium assumed to be an elastic body. Average elastic modulus of hard dental tissues is four orders of magnitude higher than elastic modulus of PDL. Both a tooth and alveolar bone can be taken to be perfectly rigid bodies. However, for estimation convenience, a tooth was treated as a deformable elastic body, alveolar bone as a perfectly rigid body. The accepted elastic constant values for PDL and hard dental tissues are given in table 2.

| Table 2. Elastic constant values. |
|---|---|
| Young's modulus (MPa) | 0.68 | 20000 |
| Poisson ratio | 0.49 | 0.3 |

Occlusal effects on dental mobility and on tooth-on-periodontium pressure were analyzed separately for vertical and horizontal component forces. Vertical forces were directed along tooth axis (figure 1), horizontal forces buccolingually. The total vertical load value was taken to be 160 N, an average masticatory load value in case of vertical occlusion [1]. Distribution of such load over individual teeth...
was set as described by [22], with due account for absence of the third molar teeth (table 3). Horizontal biting force values were taken to be half the vertical force values for grinding teeth (table 3) as set forth in [23], one-third the vertical force values for anterior teeth (table 3) following the dental edge shape analysis.

The data in table 3 was used to set stress boundary conditions at the occlusal interface (figure 1). The alveolar bone taken to be perfectly rigid, zero-displacement boundary conditions were set at the alveolar bone-to-periodontal ligament interface (figure 1).

Table 3. Vertical and horizontal biting force values.

|       | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|-------|----|----|----|----|----|----|----|----|
| Vertical force, N | 4.8 | 4.6 | 16.0 | 8.2 | 8.0 | 24.5 | 13.8 | 0 | 80 |
| Horizontal force, N | 2.4 | 2.3 | 8.0 | 2.7 | 2.7 | 8.2 | 4.6 | 0 | - |
3. Results and discussion
The calculations used ANSYS-integrated FEM. Four versions of calculations of effects vertical and horizontal forces have on the teeth given normal alveolar bone height and periodontal ligament thickness or slightly reduced osseous tissue levels were carried out. Tooth displacements, as well as displacements and stresses arising at the dental root-to-periodontium interface were analyzed. Tables 4 to 7 give maximum values of these parameters for the four calculation versions.

**Table 4.** Displacements and stresses in case of vertical forces and normal alveolar bone height.

|               | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|---------------|------|------|------|------|------|------|------|
| Maximum total tooth displacement (µm) | 30.6 | 28.7 | 46.5 | 26.0 | 14.8 | 8.6  | 4.1  |
| Maximum total displacement at dental root/PDL interface (µm) | 24.1 | 21.5 | 38.0 | 22.1 | 13.4 | 7.7  | 3.6  |
| Maximum total contact stress at dental root/PDL interface (MPa) | 0.594 | 0.431 | 0.960 | 0.578 | 0.405 | 0.350 | 0.160 |

**Table 5.** Displacements and stresses in case of horizontal forces and normal alveolar bone height.

|               | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|---------------|------|------|------|------|------|------|------|
| Maximum total tooth displacement (µm) | 37.9 | 36.3 | 82.3 | 37.7 | 17.5 | 7.3  | 5.6  |
| Maximum total displacement at dental root/PDL interface (µm) | 34.3 | 16.0 | 39.0 | 28.3 | 7.5  | 5.0  | 2.4  |
| Maximum total contact stress at dental root/PDL interface (MPa) | 0.746 | 0.169 | 0.827 | 0.406 | 0.180 | 0.150 | 0.210 |

**Table 6.** Displacements and stresses in case of vertical forces and reduced alveolar bone height.

|               | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|---------------|------|------|------|------|------|------|------|
| Maximum total tooth displacement (µm) | 49.9 | 38.3 | 63.9 | 42.5 | 20.6 | 8.9  | 4.2  |
| Maximum total displacement at dental root/PDL interface (µm) | 30.2 | 25.0 | 45.0 | 29.4 | 16.5 | 8.8  | 4.1  |
| Maximum total contact stress at dental root/PDL interface (MPa) | 0.651 | 0.457 | 1.04 | 0.645 | 0.487 | 0.802 | 0.170 |
Table 7. Displacements and stresses in case of horizontal forces and reduced alveolar bone height.

| Tooth number | 1   | 2   | 3   | 4   | 5    | 6   | 7   |
|--------------|-----|-----|-----|-----|------|-----|-----|
| Maximum total tooth displacement (µm) | 83.5 | 62.2 | 132 | 119 | 47   | 12.0 | 10.7 |
| Maximum total displacement at dental root/PDL interface (µm) | 54.4 | 25.0 | 46.0 | 45.2 | 19.2 | 7.5  | 4.1  |
| Maximum total contact stress at dental root/PDL interface (MPa) | 0.901 | 0.268 | 0.981 | 0.68 | 0.42 | 0.250 | 0.445 |

The least maximum displacements of teeth (4 µm to 47 µm) are produced by vertical forces when periodontal height is normal. Horizontal forces increase displacements (6 µm to 82 µm) about 1.7 times. Reduction in levels of the alveolar bone and the periodontium at the initial stage of periodontitis caused dental mobility to become 1.4 times higher under vertical forces (4 µm to 64 µm), and 1.6 times higher under horizontal forces (11 µm to 132 µm). The resulting displacements have the same magnitude as the dental mobility data in [23] (15 µm to 20 µm for axial force and 150 µm to 200 µm for horizontal force).

If dental mobility is increased almost 2 times, does it mean periodontium is subjected to as much higher pressure and therefore overloaded?

Tables 4 to 7 show that, when periodontal height is normal, maximum contact stresses produced by vertical forces (0.16 MPa to 0.96 MPa), are even somewhat decreased (0.15 MPa to 0.83 MPa) under horizontal forces. Reduced alveolar bone height causes contact stresses to be increased 1.1 times under vertical forces (0.17 MPa to 1.04 MPa) and 1.2 times under horizontal forces (0.25 MPa to 0.98 MPa). Furthermore, initial stage of periodontitis does not result in periodontal overload.

According to the findings, periodontal should be estimated from maximum displacement at the dental root-to-periodontium interface which produces the highest contact stress, rather than from the maximum tooth displacement (which occurs at the crown, due to the tooth rotating under load).

According to tables 4 to 7, maximum displacements at the dental root-to-periodontium interface vary as follows. When periodontal height is normal and when the forces are vertical, such displacements are within 4 µm to 38 µm. Horizontal forces bring about almost no increase in these values (2 µm to 39 µm). Reduced alveolar bone height causes these displacements to increase 1.2 times for vertical forces (4 µm to 45 µm), and 1.4 times for horizontal forces (4 µm to 54 µm). Therefore, maximum displacement behavior at the dental root-to-periodontium interface is correlated to maximum contact stress behavior.

In sum, this study yields the same stress magnitude as [17] a central maxillary incisor.

4. Conclusions
The computer tomogram was used to construct geometric models of real left-side mandibular teeth. ANSYS software was used to obtain displacements and stresses in the tooth/periodontium system given normal or reduced alveolar bone height as produced by vertical and horizontal biting forces.

Functional periodontal overload was shown to be governed by displacements at dental root-to-periodontium interface rather than by dental mobility.

References
[1] Betelman A I and Bunin B N 1951 J. Prosthetic dentistry 388
[2] Gavrilov E I and Oksman I M 1978 J. Prosthetic dentistry 464
[3] Lindhe J and Svanberg G 1974 J. Clin. Periodontol. 1 3–14
[4] Lindhe J and Ericsson I 1976 J. Clin. Periodontol. 3 110–22
[5] Polson A M, Meitner S W and Zander H A 1976 J. Periodontol. 1 279–89
[6] Ericsson I and Lindhe J 1982 J. Clin. Periodontol. 9 497–503
[7] Perrier M and Polson A 1982 J. Periodontol. 53 152–7
[8] Pihlstrom B L, Anderson K A, Aeppli D and Schaffter E M 1986 J. Periodontol. 57 1–6
[9] Jin L J and Cao C F 1992 J. Clin. Periodontol. 19 99–7
[10] Harrel S K and Nunn M E 2001 J. Periodontol. 72 495–505
[11] David E D and Brian L M 2006 J. Am. Dent. Assoc. 137 1381–9
[12] Bosyakov S M, Mselati A F and Yurkevich K S 2015 J. Bulletin of BSU 84–9
[13] Begum M S, Dinesh M R, Tan K F H, Jairai V, Khalid K M and Singh V P 2015 J. Pharm. Bioallied. Sci. 7 443–50
[14] Roostaie M and Soltani M 2017 J. Brazil. 39 2353–69
[15] Kalachev Y S, Ralev R D and Iordanov P I 2001 J. Folia medica 43 105–8
[16] Geramy A and Faghihi S 2004 J. Quintessence international 8 35–43
[17] Chen Y C and Tsai H H 2011 J. Dental Sci. 6 90–4
[18] Wang C Y, Su MZ, Chang H H, Chiang Y C, Tao S H, Cheng J H, Fuh L J and Lin C P 2012 J. FMA 111 471–81
[19] Su M Z, Chang H H, Chiang Y C, Cheng J H, Fuh L J, Wang C Y and Lin C P 2013 J. Dent. Sci. 8 121–8
[20] Nyashin M Y, Pechenov V S and Rammerstorfer F G 1997 Russ. J. Biomech. 1 84–96
[21] Dudar O I, Kosterina I P, Mayorova L V and Fateeva N A 2009 Russ. J. Biomech. 13 56–62
[22] Ryakhovsky A N and Khlopova A M 2004 J. Panorama orthopedist. Dentistry 1 18–28