SCRIPTA MEDICA (BRNO) – 76 (1): 21–28, *January 2003*

COMPUTER SIMULATION OF BONY TISSUE RESPONSE TO A PARTIAL REMOVABLE DENTURE FITTED TO A LOWER JAW

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A b s t r a c t

Mathematical simulations in dentistry can be used for evaluation of conditions that arise in bone due to restoration of dental defects by prosthetic treatment. This study was concerned with stress distribution around an abutment tooth in the mandible fitted with a partial removable denture. On the basis of computed tomography data from a real edentulous jaw, a three-dimensional model of the mandible was constructed and completed with models of an abutment tooth (first premolar) and periodontium. The load imposed on the tooth by mastication forces of the musculus temporalis and musculus masseter and the load imposed by a partial removable denture attached to the abutment tooth in either suprabulge or infrabulge areas of its crown were calculated and expressed, as stress intensity (σ_{red}), in MPa. The simulation showed that, around the abutment tooth, the maximal σ_{red} value was on the vestibular side of the jaw, at the site where bone resorption occurred. These values differed markedly when the abutment was subjected only to a physiological load or when the load was imposed by a partial denture (3.9 MPa *vs* 13.7 to 18.8 MPa). The simulation also revealed that the mode of denture attachment, by either an occlusially or gingivally approaching clasp, affected stress distribution in the bony tissue involved and increased the σ_{red} value by 8 to 16 %. In conclusion, mathematical simulation offers a method for assessment of the response of a jaw to loads imposed by prostheses before therapy is commenced; this is of great value particularly in extensive or rare dental defects.

K e y   w o r d s

Mathematical model, Mandible, Abutment tooth, Dental defect, Dental restoration, Stress distribution, Bone resorption

INTRODUCTION

The present era is characterised by the spread of computer technologies into nearly every sphere of human activity, with dental medicine not excluded. Computer simulation can be used with advantage for the assessment of mechanical load imposed on teeth or jaws, in which different tooth shapes, different tooth number and various mastication forces can be considered (*1*). In prosthetics, mathematical modelling enables us to predict stress distribution in the bony tissues supporting a dental restoration or its parts under different conditions that may exist in the mouth of a patient. It is possible, for instance, to estimate the sites subjected to the highest potential load of a denture before this is made and fitted. On the basis of mathematical models it can be calculated what load will be imposed on the sites of clasp attachment or sites of contact between a restoration and the adjacent teeth and tissues, and thus optimise the reconstructive procedure.

A shortened dental arch, either uni- or bilaterally, is a frequently occurring dental defect (*2*). Restoration of this defect with a partial denture may often result in induced resorption of bony tissue, which may be both fast and substantial (*3*). Resorption is usually observed at those sites of contact between a restoration and the jaw where there is a maximum load due to the effect of mastication forces on the denture body, i.e., around abutment teeth. The aim of this study was to simulate stress distribution in the mandible that was fitted with a partial removable denture by means of a clasp placed in either the suprabulge or the infrabulge crown area of a tooth, and to use the results of simulation to show the extent of and progress in bone resorption and to compare the calculations with real situations in dental practice.

MATERIALS AND METHODS

For mathematical simulation, the finite element method (FME) was used (*1, 4*). The mathematical model for distribution of stress in the lower jaw was constructed for a partial removable denture with a clasp attached at the first premolar at either the suprabulge or the infrabulge region because, in prosthetics, this restoration is used most frequently to treat of defects of a shortened dental arch.

Our model was based on digitalised data, obtained by computer tomography examination of an edentulous lower jaw (*5, 6.*), and processed by an ANSYS finite element system (*7*). The model was completed with the geometrical model of a tooth, which had a single root and was placed in the first premolar's position**,** and with the model of a periodontium (*Fig. 1*) in a simplified form to make calculations easier. The tooth was represented by an image composed of two truncated cones adjoining at their bases and the periodontium was represented by a hollow truncated cone with a constant wall thickness. To simulate the effect of a denture, the forces acting on the abutment tooth and corpus mandibulae were calculated. The jaw bone was taken as being homogeneous and isotropic in structure and the values of modulus of elasticity E = 5 509 MPa and Poisson number m = 0.34 were used. The isotropic and linear properties of cortical and spongious bone were considered. The tooth was characterised as a homogeneous and isotropic continuum with E = 10 000 MPa and m = 0.3. The values for the periodontal ligament were E = 100 MPa and m = 0.45 (*8*).

The magnitudes and directions of forces acting on the tooth and the relevant tooth displacement were defined (*9*). For mathematical modelling, a rectangular coordinate system (x, y ,z) was adopted, the origin of which was identical with the centre of gravity of the tooth surface. The tooth was loaded with a resultant force that, in relation to the coordinate system, had a general direction. The force acting along the vertical axis of the tooth and representing mastication forces of the m. temporalis and m. masseter was designated F_{4y}.

The model was based on parameters of symmetry because the jaw bone can be considered symmetrical in the median plane. The effect of only two muscles, i.e., m. temporalis and m. masseter, on the denture was simulated. The effect of the m. pterygoideus medialis was included in the force of m. temporalis because the attachment site of their ligaments and direction of their forces are very similar. In the ANSYS programme, bone responses in the region between tooth 4 and 8

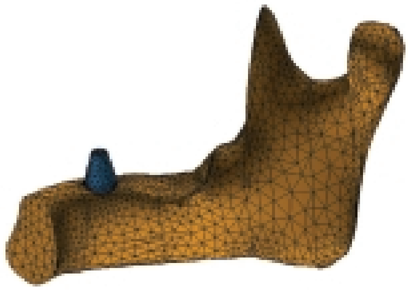

Fig. 1
Three-dimensional geometric model of a lower jaw with the first premolar (blue cone).

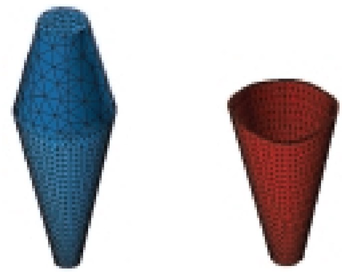

Fig. 2
Three-dimensional models of the first premolar (left) and periodontium (right).

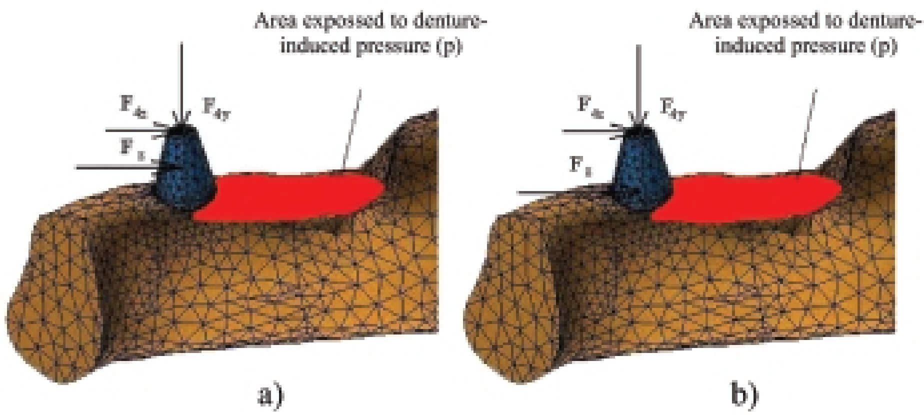

Fig. 3
Three-dimensional model showing areas of loads imposed on a tooth to which a partial denture is attached by a three-arm clasp; blue cone, abutment tooth; red area, surface under the body of a denture; F_{4z}, F_{4y} and F_z, loads imposed on the tooth; (a) infrabulge bulge clasp attachment; (b) subprabulge clasp attachment.

were defined in the manner that eliminated tooth displacement along axes y and z on the bone surface. For each tooth, a separate calculation was made. The following situations were considered:

Simulation 1 (not illustrated). The first premolar was subjected to a physiological load and stress distribution in the surrounding tissues was calculated. The force (F) imposed on the tooth had only two components, F_{4y} and F_{4z}, corresponding to m. masseter and m. temporalis mastication forces.

Simulation 2. A removable partial denture was attached to the firth premolar and the body of the denture was supported along the whole length of the corpus mandibulae (tooth positions 5 to 8). The forces acting on each of the artificial teeth were calculated and related to the abutment tooth and the region of the corpus mandibulae between teeth 5 and 8). An occlusially approaching clasp with F_z acting on the middle of the crown in a transversal plane was considered (*Fig. 3a*).

Simulation 3. The calculation was as in simulation 2 but, this time, a gingivally approaching clasp associatde with force F_{4z} acting on the tooth neck area close to the gingival was considered (*Fig.3b*).

The loads on the abutment tooth and the corpus mandibulae were calculated according to the following formulae:

Load on the abutment tooth in the vertical direction, $F_{4y} = 40.2$ N.

Load on the abutment tooth along axis z , $F_{4z} = 14.4$ N.

Total load on the abutment tooth imposed by a clasp along axis z,

$$F_z = F_{5z} + F_{5z} + F_{5z} + F_{8z} = 14.4 + 14.4 + 14.4 + 14.4 = 57.6 \text{ N.}$$

Loading pressure on the corpus mandibulae

$$p = \frac{F_{5y} + F_{6y} + F_{7y} + F_{8y}}{S} = \frac{43.2 + 48.2 + 55.9 + 70.7}{230} = 0.95.\text{MPa}$$

where F_{4z}, F_{5z}, F_{6z}, F_{7z} and F_{8z} are load components acting on teeth 4, 5, 6, 7, 8 along axis z, F_{4y}, F_{5y}, F_{6y}, F_{7y} and F_{8y} are loads on teeth 4, 5, 6, 7, 8 along axis y, and S is a surface subjected to the load.

For the interpretation of numerical results of simulation, stress intensity in the bone was characterised by σ_{red} according to the HMH conditions of plasticity (Misses) (*10*).

RESULTS

In a partial removable denture attached by means of a clasp, the simulations showed different values of stress distribution according to the mode of approach. In simulation II (occlusialy approaching clasp), the value for σ_{red} increased to 15.0 MPa and, in simulation III (gingivally approaching clasp), σ_{red} had a value of 13.7 MPa. The difference in stress distribution between these two method of attachment was 1.3 MPa. In simulations II and III shown in *Figs 7 to 7*, stress distribution and its intensity are illustrated by means of spectral colours on a scale from red (maximum) to blue (minimum). Overall, the approach of a clasp led to an increase in σ_{red} value by 8 to 16% according to the mode of clasp approach. Gingival clasp approach resulted in a lower value of σ_{red} stress, i.e., in the slower progress of bone resorption in the vicinity of the abutment tooth.

DISCUSSION

In this study, the maximum values for σ_{red} characterising stress distribution in tissues in the first premolar's vicinity were in agreement with the data reported in

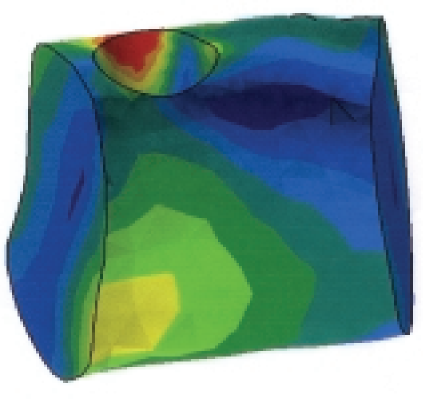

Fig.4
Simulation II. Stress distribution and its intensity shown by spectral colours from red (maximum) to blue (minimum); vestibular view.

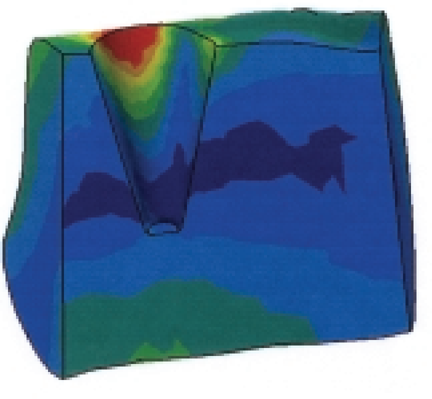

Fig. 5
Simulation II. Stress distribution and its intensity shown by spectral colours from red (maximum) to blue (minimum); cross-sectional view.

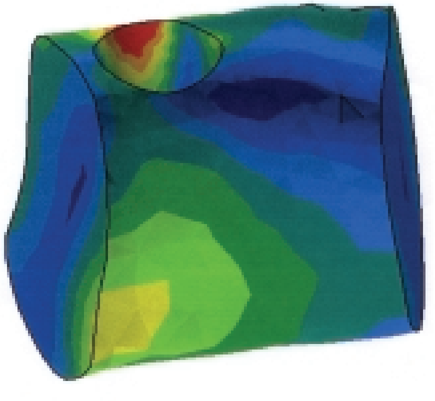

Fig. 6
Simulation III. Stress distribution and its intensity shown by spectral colours from red (maximum) to blue (minimum); vestibular view.

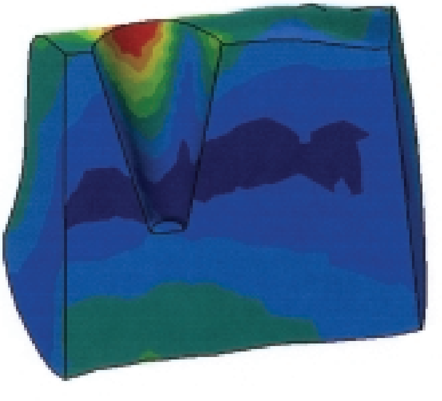

Fig. 7
Simulation III. Stress distribution and its intensity shown by spectral colours from red (maximum) to blue (minimum); cross-sectional view.

the relevant literature. *Papavasiliou et al.* (*11*) found the maximum value of σ_{red} to be 15.0 MPa in the cortical bone region in the close vicinity of a dental implant supported by an edentulous jaw. Our previous studies concerning the mathematical simulation of stress distribution in jaw bone also showed σ_{red} values in the range of 10.1 to 15.5 MPa, which was related to the position of an abutment tooth, mode of denture attachment or shape of a dental implant (*4, 7, 12*).

The finding of the maximum σ_{red} value in bone on the vestibular side of an abutment tooth corresponds to what is know from prosthetic practice. This region, i.e., the vestibular and near distal sides of the first premolar, undergoes the greatest bone resorption. In addition to this maximum, another bone region found to be subjected to resorption was that distal to the abutment tooth (σ_{red} = 9.6 MPa). In clinical practice, this region is characterised by resorption of the bone under the body of a denture. This implies that the results of mathematical simulation provide valuable assistance in explaining the fact that resorption is located to this particular region.

Our simulated models have important implications for prosthetic dentistry. The restoration of extensive dental defects by a partial denture in a jaw with a shortened dental arch results in bone resorption due to the effect of stress distributed in the vicinity of an abutment tooth. The progress of bone resorption can be slowed down by an alternative approach that is based on placement of a central implant in the distal jaw and fitting a permanent denture by means of matrix and patrix attachments, which reduces the load imposed on the last abutment tooth (*13*). This type of restoration, as compared with a partial removable denture, will result in less trauma to bony tissue and minimal progress in bone resorption. Our previous clinical experience (*2*), given support by the results of histomorphological studies (*13*), has confirmed that when defect restoration is based on the use of a bridge, bone resorption is non-existent or is only very low.

Our further research using mathematical simulations will be focused on more complex situations related to partial denture attachment in a shortened dental arch and on identification of other jaw regions that are at risk of developing resorption. The application of the results of mathematical simulation to the early stages of prosthetic management in extensive or rare dental defects showed that the possibility of risk evaluation for different approaches to treatment before this is started permitted the use of methods that had minimal adverse effects on the health of jaw bone involved.

Acknowledgement

The authors wish to thank Professor P. Krupa, Head of the Department of Radiodiagnostic Imaging, Faculty of Medicine in Brno, for providing the original computed-tomography.

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POČÍTAČOVÁ SIMULACE ODEZVY KOSTNÍ TKÁNĚ DOLNÍ ČELISTI NA PARCIÁLNÍ NÁHRADU

Souhrn

Matematická simulace může být ve stomatologii použita pro ověření podmínek vznikajících v kostní tkáni při protetických úpravách. Článek je zaměřen na matematickou simulaci napětí v dolní čelisti zvláště v okolí pilířového zubu částečné snímatelné náhrady. Na základě údajů zjištěných počítačovou tomografií na reálných čelistech byl vytvořen trojrozměrný model dolní čelisti, který byl doplněn o model pilířového zubu (první premolár) a model parodontu. Bylo simulováno působení žvýkacích sil musculus temporalis a musculus masseter na geometrický model prvního premoláru a částečnou snímatelnou náhradu kotvenou na tento zub pomocí trojramenné spony s vysokým a nízkým odstupem. Matematická simulace ukázala, že maximální hodnota redukovaného napětí σ_{red} byla v oblasti pilířového zubu na vnější straně čelisti, kde docházelo resorpci kosti. Hodnoty redukovaného napětí σ_{red} se však výrazně lišily: 3,9 MPa u jednotlivého zubu, 13,7–18,8 MPa u snímatelné náhrady. Rovněž bylo zjištěno, že způsob použití kotevních prvků může zvýšit nebo snížit hodnotu σ_{red} přibližně o 8–16%. Matematická simulace ukázala, že je účinným prostředkem při stanovení kritických oblastí čelisti zatížených tlakem konstrukčních prvků náhrady, ve kterých lze očekávat resorpci kosti.

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