

Stress distribution in anchoring regions of posts cooperating with overdentures

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The paper presents the results of model research of mechanical compatibility of selected overdenture structures. The tests based on finite elements method were conducted on flat models reflecting the areas of posts anchoring in a sagittal plane. The reference point was the structure of a prosthesis seated on ball-and-socket joints secured in tooth roots. As alternative solutions, dentures placed on two cylindrical implants supporting ball-and-socket joints were compared with a denture attached to a joint which consisted of a straight axis bar and an elastic clip as well as with a denture supported by a joint of elevated retention, built of a doubly bent axis bar and three elastic bar clips. Taking advantage of the MES Algor program functions, the diverse material structures of the systems investigated were modelled. Next, the reduced stresses σ_{red} and principal maximum stresses σ_1 generated in osseous tissues, in the implants anchoring area, were determined. The value of the mechanical stimulator decisive to the osseous tissue remodelling was assumed as an evaluation criterion. It was assumed that making use of patient's own tooth roots to attach implants is an optimal solution which, in terms of mechanics, is practically identical to the alveolodental ligament of a healthy tooth. The application of the other methods of implanted prosthesis attachment always creates a risk of undesirable changes, mostly in the upper area of post insertion into the osseous tissue. The least favourably, in the light of stresses comparison, looks the

joint of a doubly refracted axis, where the probability of adverse changes of the osseous tissue in a short time is high. This indicates the necessity to carry on works in order to improve this solution characterized by good retention.

Key words: implants, overdentures, finite elements method, reduced stresses, principal stresses

1. Introduction

Among the applied solutions relating to implanted dentures a particular role is played by overdentures supported by two implants and the oral cavity mucous membrane [1], [2], [3]. Such solutions enhance the comfort of using the prostheses when compared to acrylic complete dentures; however, the load on posts generated during chewing is considerable. According to the action and reaction principle, the load is transmitted directly onto the osseous system in the implants-anchoring region, thus changing the natural stress trajectories. The significance of this problem arises from the fact that one of the factors that influence the osseous tissue remodelling processes are mechanical stimulators. The stress pattern and values have an impact on the mineralization processes and on the orthotropic properties of the osseous tissue [4], [5], [6]. Both excessive falls (causing demineralization of the osseous tissue) and rises of stress, which can induce osteolysis, affect adversely the “quality” of bones [6]. Due to the adjusted to occlusive loads local properties of the jaw and mandible cortical bone [7], [8], one should assume that another undesirable phenomenon are changes of the principal stresses’ directions.

Due to the complexity of the problem presented, the information provided by available literature on the above mentioned phenomena is far from a comprehensive clarification.

The study presented belongs to the research on the model systems consisting of natural tissues and implants. An assessment of mechanical biocompatibility was made by analyzing the stress distributions in the anchoring regions of implants cooperating with three selected types of joints applied in overdentures. As a reference point, being close to the natural state from the mechanician point of view, a solution was assumed where the tooth roots were used to attach the prosthesis joints.

2. Methodology

The forecast of the success is mainly based on the results of clinical observations of implanted prostheses of different types, published by numerous authors. In many cases, however, the solutions presented prove not to be fully justified and the benefits that result from their application are short-term. For the understanding of the essence of success stemming from the application of a post implanted into the osseous tissue, an analysis of the denture operation mechanism is essential. The aim of this study was to

carry out model research of stresses in the anchoring regions of posts which cooperate with selected denture attachment systems applied in the clinical practice. The basis for selecting the solutions to be analysed were the authors' own clinical experiences.

The most popular and relatively cheap load-bearing structure of an implanted prosthesis of an overdenture type consists of a system of two implant posts, fixing elements which ensure denture retention and central bars, on which reproduced alveolar arches are located. The retention elements are most often detachable ball-and-socket or cylindrical joints. The former ones consist of a small metal ball and a resilient cap placed onto it (implant female and denture cap male), whereas cylindrical joints consist of a load-bearing bar and elastic clips placed onto them [2].

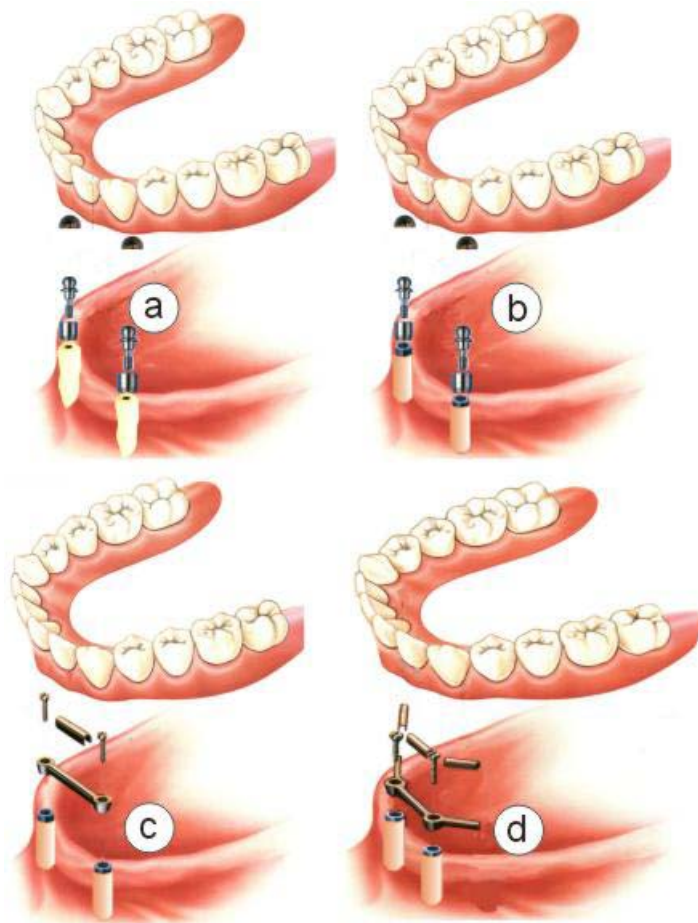


Fig. 1. Four attachment variants being compared:
a – by ball-and-socket joints attached to patient's own tooth roots,
b – by ball-and-socket joints screwed into implants, c – by a joint consisting of a straight axis bar,
d – by a joint consisting of a doubly bent axis bar

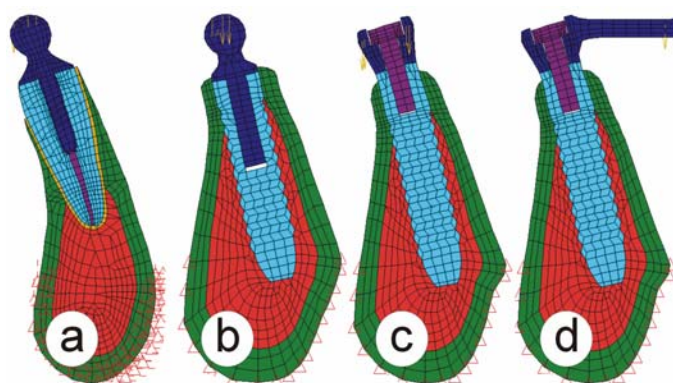


Fig. 2. View of models reflecting the structure of implant posts anchoring areas in sagittal sections

Figure 1 presents the cases for which it was decided to determine the biocompatibility of loads of the posts anchoring regions. These practical solutions created the basis for building the flat numerical models shown in figure 2, which reflect the structure of the posts anchoring regions in sagittal sections. An idea of a spatial representation of the object was given up since in a lot of cases, flat models [9], easier to build, are fully sufficient to reflect the mechanical essence of this phenomenon. The investigations were conducted using the finite elements method, with the application of the MES Algor program. The following designations of the models have been introduced:

- model a – attachment by ball-and-socket joints fixed to patient's own tooth roots; this solution, the closest to the natural state, was regarded as the reference point for further analyses;
- model b – attachment by ball-and-socket joints screwed into implants;
- model c – attachment consisting of a straight axis bar and two elastic bar clips,
- model d – attachment consisting of a doubly bent axis bar and three elastic bar clips.

The values of Young's modulus (E) and Poisson ratio (ν) assumed for the calculations to map the material structure of the system analyzed are presented in table 1. The models were loaded with 100 N force, in accordance with the results of prior occlusion forces' investigations [10], [11]. In addition, for the screw joints screwed into implants, the initial stresses caused by tightening the screw were modelled.

Table 1. Young's modulus and Poisson ratio values for individual model components

Material	E (MPa)	ν
Steel	20000	0.3
Titanium	12000	0.34
Cortical bone	17000	0.33
Spongy bone	600	0.41
Periodontium	40	0.45

After completion of the models' calculation cycle, detailed values were read of stresses in central points which reflect:

1. The changes of maximum principal stresses σ_1 :

- at bone/periodontium border (model a), on labial and glossal sides,
- at implant/bone border (models b, c and d), on labial and glossal sides,
- in the cortical bone, on labial and glossal sides (models a, b, c and d).

2. The changes of reduced stresses σ_{red} in the cortical bone, on labial and glossal sides (models a, b, c and d), determined according to the Huber–Mises hypothesis.

The stresses were read beginning with the place of implant insertion into the alveolar process, shifting gradually in the direction of its sinking (g). In order to reduce the impact of the way of arrangement of grid points on the results of readings, a few readings were made at each level, in the points located within the area analysed.

For further analyses, maximum values were selected. The results obtained in such a way are presented as the dependence $\sigma(g)$ which determines, using the least squares method, the trend line described by the third- or fourth-degree polynomial:

$$y = b + c_1x + c_2x^2 + c_3x^3 + c_4x^4,$$

where:

y – the values of reduced stresses (σ_{red}) or principal stresses (σ_1),

x – the distance of the layer under consideration from the point of implant entry into the bone (g).

The results of numerical calculations and statistical analyses are presented in the form of stress maps and diagrams which show the results after their statistical analysis.

3. Research results

Maps illustrating the distribution of maximum principal stresses σ_1 are presented in figure 3. The map scales have been artificially reduced so that the largest possible number of details could be presented to show clearly the differences between the models compared. Stresses in a scale reflecting the computed values are presented on collective diagrams $\sigma_1(g)$ in figure 4.

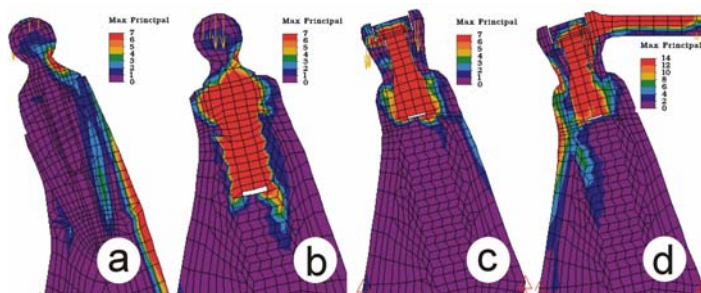


Fig. 3. Maps of principal stresses σ_1 for models a, b, c and d

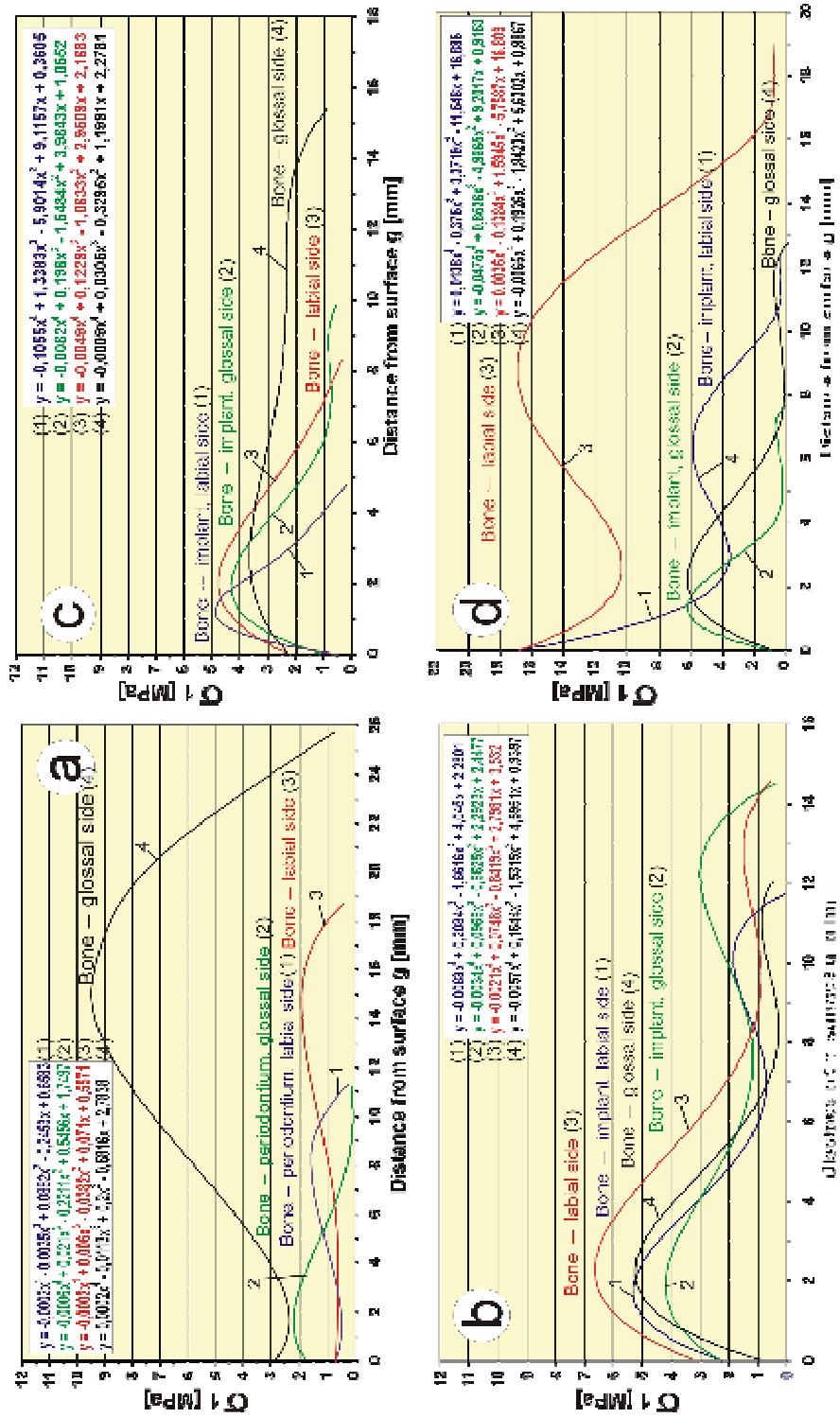


Fig. 4. Changes of principal stresses σ_1 as a function of distance (g) from the implant entry point

As visible in figure 4, the maximum principal stresses σ_1 on glossal side reach, for model a, ca. 3 MPa in the upper part of the alveolar process and increase with shifting deep into the bone; they reach the highest value of 11.36 MPa in the bone, with g equal to 15.5 mm and after this point, they fall. On labial side, σ_1 does not exceed 2.5 MPa and the stress values fluctuate between 0.5 and 2.5 MPa. There are no visible areas with a considerable stresses concentration there. In model b, the stresses rise from 1–3 MPa to 7.4 MPa on glossal side and to 8.83 on labial side with g equal to ca. 2 mm. Next, the stresses fall and reach stable values between 5 and 1 MPa. In the case of model c, a rise of stresses σ_1 has been noticed from the value of ca. 1.5 MPa to 5.29 MPa on labial side and 4.75 MPa on glossal side with g ranging from 1 to 3 mm. After that, the stresses on labial side drop rapidly below 1 MPa with g of 7 mm, whereas on glossal side, they remain within the range of 1–3 MPa. In model d, an increase of σ_1 values is observed up to 6.66 MPa ($g = 2.5$ mm) with a subsequent fall of stresses below 0.5 MPa to the depth of 5 mm. On labial side, a fall of σ_1 is visible from a maximum value of 21.3 MPa in the implant insertion area to ca. 10.5 MPa with $g = 3$ mm; after that a rise of σ_1 occurs to the relative extremum of 18 MPa at 9 mm depth with a subsequent stress reduction.

Maps illustrating the distribution of reduced stresses σ_{red} in accordance with the Huber–Mises hypothesis are presented in figure 5. Figure 6 shows the trend lines which reflect the changes of reduced stresses in the cortical bone as a function of the distance of the layer in question from the alveolar process upper surface (g).

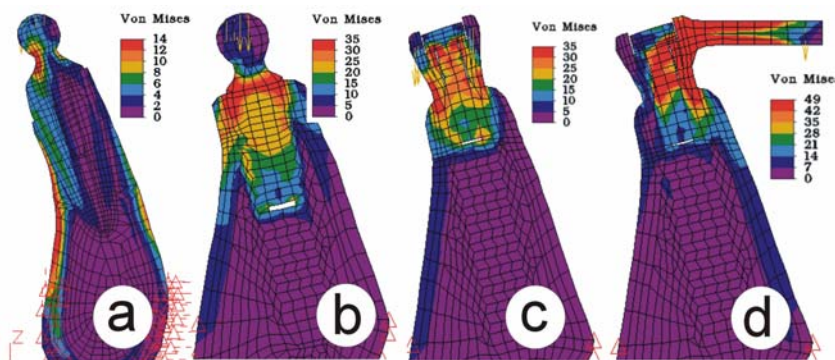


Fig. 5. Maps of reduced stresses according to the Huber–Mises hypothesis σ_{red} for models a, b, c and d

The “high” bone of alveolar processes in model a takes over the loads at stresses not exceeding 21 MPa. The maximum stresses both on labial and glossal sides are located in the areas at an 11 to 15 mm distance from the alveolar process surface. The reduced stresses in model b reach their maximum values in the area of implant insertion and quickly fall with shifting deep into the bone. The element under the greatest effort is the cortical bone on labial side (max 50 MPa). The maximum reduced

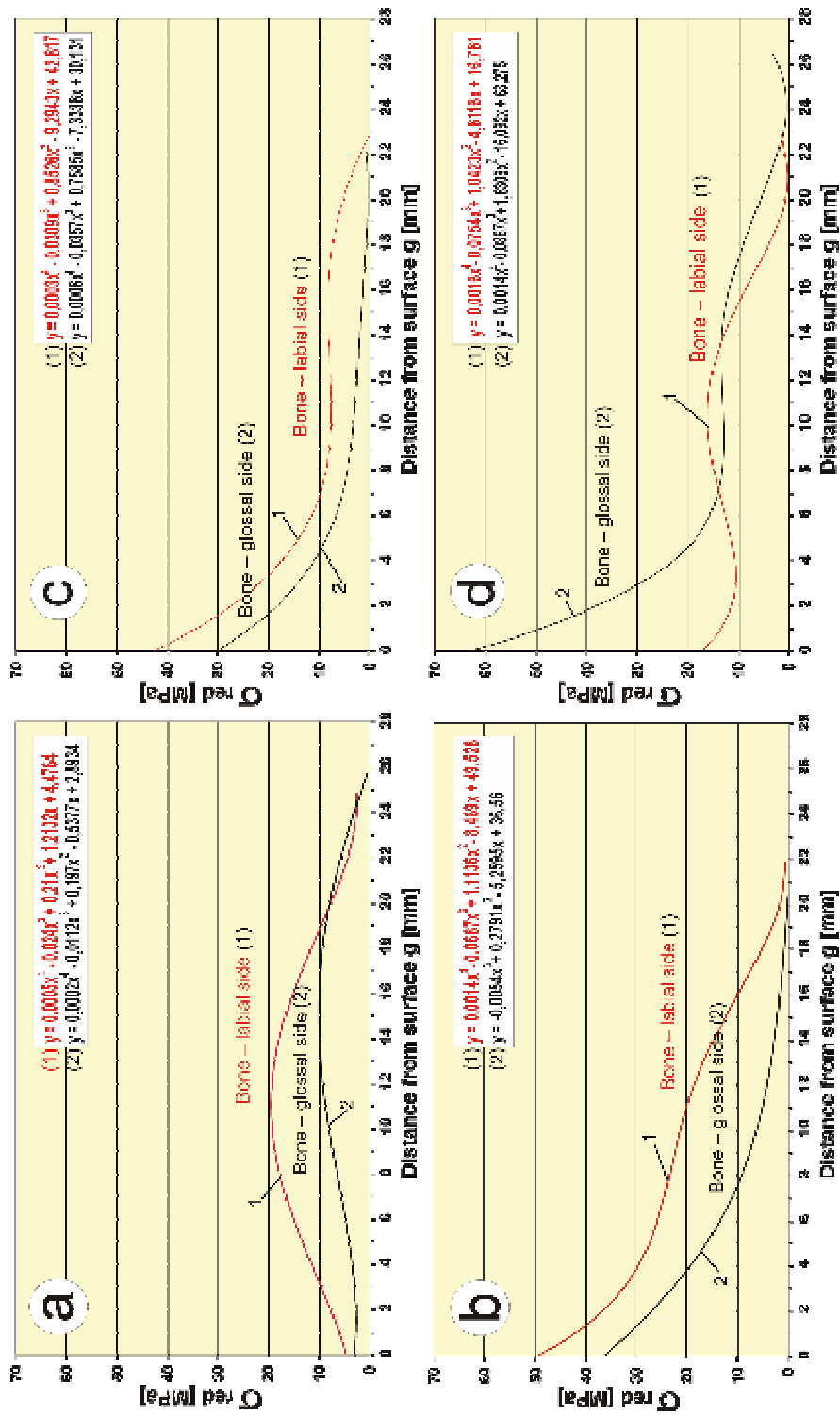


Fig. 6. Changes of reduced stresses σ_{red} in cortical bone as a function of the distance g from the implant entry point

stresses in the load-bearing structure amount to 86 MPa. In the case of model c, the maximum stresses are observed on labial side, where they reach 43 MPa. When going deep into the bone, these stresses fall and reach stable values at the depth of ca. 5 mm. The maximum reduced stresses in the load-bearing structure amount to 98 MPa. In model d, a considerable rise of stresses is observed which in the cortical bone on glossal side reach as much as 70 MPa; this constitutes twofoldness of the stresses which occur in the corresponding area in model b and is ten times as much as in model a. The maximum reduced stresses in the load-bearing structure amount to 398 MPa.

4. Discussion of the research results

In the investigations, the principal stresses σ_1 were assumed to be physical quantities stimulating the osseous tissue to its remodelling. Taking advantage of the available literature data, threshold values of the osseous tissue mechanical stimulator were assumed between 1.5 and 4 MPa [6]. Based on the analysis of reduced stresses σ_{red} , a probable response was determined of the osseous tissue to the load which occurs when the denture is working. Next, the stresses obtained were compared with the information about the osseous tissue response to mechanical stimuli. For this article, the data relating to deformation quantities provided in paper [6] were translated (using Hook's law) into stress values. In this way, the values juxtaposed in table 2 were obtained. They allow an estimation of the threats that the loading of anchoring areas brings with itself.

Table 2. Osseous tissue response to loads (based on [6])

Load nature	Deformation quantity $\varepsilon [\times 10^{-4}]$	Stress value (MPa)	Osseous tissue response
Failure loads	150–200	255–300	Distributive failure
Pathological overloads	>40 (ca. 60)	>68 (102)	Resorption, microcracks (plastic strain)
Elevated physiological loads	20–40	34–68	Mineral phase increase
Physiological loads	2–20	3.4–34	Physiological equilibrium
Underloads	<2	<3.4	Mineral phase decrease

It was assumed that making use of patient's own tooth roots (model a) to fasten support elements is an optimal solution owing to practically identical loads of bones of alveolar processes as in the case of patient's own teeth. Where such solution is applied, the possibility of the osseous tissue remodelling occurs only on a small area on glossal side. The existing alveolar process bone transmits loads of 3 to 20 MPa which guarantee the right mechanical stimulation of the osseous tissue and should

ensure its physiological equilibrium as well as maintaining the tissue in a good condition. Furthermore, there are no regions with elevated effort in the post's metal part, which results from the fact that the implant pin or crown finished with a ball, used as an alternative solution, is placed practically without initial stress.

A higher risk of undesirable changes in the osseous tissue was noticed for models b and c. Exceeding of the assumed threshold values of the mechanical stimulator was observed both on labial and glossal sides, on relatively large bone surface areas. An analysis of diagrams of the changes in reduced stresses corroborates the possibility of disturbing physiological equilibrium of the osseous tissue. Taking into account the values shown in table 2, one should expect an increase of the mineral phase for both solutions. We know from practice, however, that we have to do with perimplant osseous tissue atrophy in those areas. This means that in the case of stomatological implants, mechanical stimuli are not the only factors that influence the condition of bones in their surface layers. The lack of epithelial attachment, which "seals" the natural tooth socket of the model, may be conducive to biological changes in the osseous tissue. Thus, the threshold values of stimulating stresses determined for a healthy bone will certainly fluctuate, depending on a number of phenomena that cannot be defined by mathematical formulas.

In model d, a considerable increase of the stresses σ_1 and σ_{red} is observed. Exceeding of the assumed higher threshold values of the mechanical stimulator was observed both on labial and glossal sides. On labial side, σ_1 reached 21 MPa (10 times as much as in the analogous area in model a). The reduced stresses in the cortical bone on glossal side can even reach 70 MPa, which is twice as much as the values of stresses that occur in the corresponding area in model b and ten times as much as in model a. The data obtained show high probability of quick occurrence of resorption or microcracks in that region.

5. Conclusions

1. Using patient's own tooth roots to place overdenture posts can be regarded as an optimal solution from the biomechanician's point of view.
2. Application of an overdenture supported by two ball-and-socket joints screwed into implants or an overdenture placed on a joint consisting of a straight axis bar induces inconsiderable local stress rises.
3. Application of a joint consisting of a doubly bent axis bar causes significant exceeding of the stress range tolerated by osseous tissues; this means a high risk of quick changes in the alveolar process bone as a result of a substantial increase of stresses in the osseous tissue surface layers.
4. Transmission of occlusive loads by the protruding beyond the outmost posts bar endings results in overload of the load-bearing structure, which necessitates a modification of the joint with a doubly refracted axis, so that it would be possible to

reduce the effort of the structure and implant anchoring areas, simultaneously keeping increased retention.

Bibliography

- [1] MAJEWSKI S., *Podstawy protetyki w praktyce lekarskiej i technice dentystycznej*, SZS-W, Kraków, 2000.
- [2] SCHROEDER A. et al., *Oral Implantology Basics ITI Hollow Cylinder System*, Thieme, Stuttgart, 1996.
- [3] SPIEKERMANN H. et al., *Implantology*, Thieme Medical Publishers Inc., New York, 1995.
- [4] ASHMAN R.B., VAN BUSKIRK W.C., *The elastic properties of a human mandible*, Adv. Dent. Res., 1987 Oct., (1), 64–7.
- [5] MARTIN R.B., BURR D.B., *Structure, Function, and Adaptation of Compact Bone*, Raven Press, New York, 1989.
- [6] MILEWSKI G., *Wytrzymałościowe aspekty interakcji biomechanicznej tkanka twarda–implant w stomatologii*, Z.N. Pol. Krakowskiej, Mechanika, nr 89, Kraków, 2002.
- [7] TAMATSU Y., KAIMOTO K., ARAI M., IDE Y., *Properties of the elastic modulus from buccal compact bone of human mandible*, The Bulletin of Tokyo Dental College, May 1996, Vol. 37, No. 2.
- [8] MILEWSKI G., TRACZ M., *Analiza numeryczna problemu anizotropii własności mechanicznych kości żuchwy*, Acta of Bioengineering and Biomechanics, Wrocław, 1999.
- [9] DEJAK B., MŁOTKOWSKI A., *Analiza naprężeń w modelach dwu- i trójwymiarowych zębów badanych metodą elementów skończonych*, Protetyka Stomatologiczna, Warszawa, 1994, nr 4.
- [10] CHLADEK W., LIPSKI T., *Metoda badania sił zgryzu wykorzystująca deformację plastyczną próbek z blachy aluminiowej*, Inżynieria Materiałowa, 1998, nr 2.
- [11] CHLADEK W., LIPSKI T., KARASIŃSKI A., *Experimental evaluation of occlusal forces*, Acta of Bioengineering and Biomechanics, 2001, Vol. 3, No. 1.