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INFLUENCE OF CANTILEVER LENGTH ON STRESS DISTRIBUTION IN PERI-IMPLANT BONE WITH FULL DENTAL ARCH ON FOUR IMPLANTS CONCEPT

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Key words: peri-implant bone, cantilever, FEM.

Summary

Background and Objective. The full dental arch on four implants concept is a useful therapy in the treatment of an edentulous mandible. Few studies have shown the effect of the cantilever length on the peri-implant bone. The aim of the study was to clarify the influence of the cantilever length on the stress and their distribution in the peri-implant bone.

Material and Methods. For research purposes, 3-dimensional finite element analysis models based on the highest atrophy of an edentulous mandible were constructed. Four dental implants were inserted in interforaminal segment in 4 conditions. The implants were splinted with a 14-unit bridge. A load of 300 N was applied to the occlusal surface at the end of the cantilever. Results. The lowest peri-implant stresses around the distal implant were in the scheme 4-2-2-4; they were by 1% greater in the scheme 4-1-1-4, by 16.7% greater in the scheme 4-3-3-4 and by 71% greater in the scheme 3-2-2-3. The greatest stresses of distal implants peri-implant bone and the lowest bone stresses of central implants were observed in the 3-2-2-3 scheme. A longed cantilever significantly increased the peri-implant overloading around a distal implants in all cases.

Conclusions. The research showed that stresses were formed around all implants during a functional load on the cantilever. The lowest peri-implant stresses were recorded when the implants were positioned according to the 4-2-2-4 and 4-1-1-4 scheme. A shortened cantilever significantly reduced the peri-implant overloading around a distal implant up to 358%.

Introduction

The treatment of the chewing function with dental implants in rehabilitation was started already in the 1960s and since then there have been great advances in the treatment planning and engineering of structures allowing doctors to help patients and plan long-term results. The problem of edentulism has been topical not only in Lithuania, but in other countries too. According to the study carried out in Kaunas city during 2006-2008, there were 5.6% of edentulous people in the 55–64-year age group and 15.2% in the 65–72-year age group (1). There has been a similar situation in other European countries: edentulous people make up 22.6% of people in the 65–74-year age group in Germany and 13.8% in Switzerland (2). In groups of people older than 80 years the percentage of edentulous people can reach 40% (3).

The full dental arch on four implants concept of the treatment with implants forming fixation for fixed dental prostheses has been created for the rehabilitation of the chewing function in patients with an edentulous mandible. Because of atrophic changes of an edentulous mandible, 4 dental implants insertion is performed in the segment of the mental foramina, and the whole dental arch is fixed on them with bilaterally distal cantilevers in the molar region (4, 5).

Complications related to dental implants and prostheses with cantilevers can be divided into biological and mechanical sections. According to retrospective 5-year analyses, biological complications comprise about 5.7% of cases; meanwhile, mechanical complications, e.g., porcelain fracture, are more frequent, comprising 10.1% of cases; fixation screws loosening and breaking comprise 7.9% and 1.6%, respectively (6).

During biting and chewing, the system of prosthesis and dental implants is affected by cyclical physiological

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loads of different directions. According to the performed research, an implant in the area of the first molar tooth can be shortly affected by a maximum load of 847 N in men and 595 N in women (7). The chewing load is absorbed and amortized by the periodontal ligament around the dental root, which is impossible in case of a connection between a dental implant and the peri-implant bone. Thus, occlusal loads directly affect implant abutments through dental prosthesis; and through them implants themselves. Finally, the peri-implant bone are affected too. Because of the differences of this amortization property the frequency of complications in case of prosthesis with cantilevers on implants is statistically greater than in case of prosthesis with cantilevers fixed on teeth, i.e., 18.2% vs. 10.9%, respectively (8-10).

In vitro investigations of dental implants and of bridges with cantilevers showed that due to occlusal load stresses concentrated around the margins of a bone-implant and especially around the implant closer to the cantilever. Researchers raised a hypothesis that a formed functional load caused overloading in the peri-implant bone, which enhanced the risk of bone tissue resorption (11). The volume of bone tissue resorption around implants and together a hypothesis raised by Zampelis et al. was confirmed by the study published by Aglietta et al. the results of which demonstrated that bone tissue resorption was 2.21 times greater around the implants closer to the cantilever in comparison with other implants (12).

One of the in vitro possibilities to study dental implants is the finite element method (FEM). It is a numerical method, which analyses stresses and deformations in structures of different geometry as well as the stability of these structures. Due to a universal nature of the research, FEM has been one of the most attractive computer research methods since the 1960s (13) and has been widely applied in dentistry for a few decades. The method consists of a few steps starting with the 2-dimensional and 3-dimensional modeling of the studied objects. The obtained results allow accurate evaluation of treatment possibilities with respect to biomechanical aspects. It is only important to create models most accurately corresponding clinical conditions (14-16).

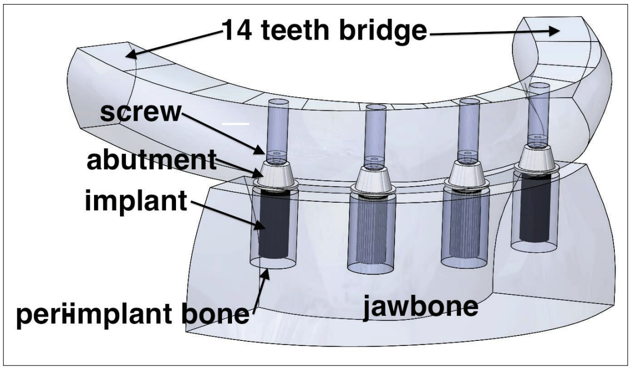

Fig. 1. Components of model

The aim of the study was to determine the influence of the cantilever length on the stress distribution in the peri-implant bone within the full dental arch on four implants concepts using the finite element analysis.

Material and Methods

For research purposes, 3-dimensional form system elements were modeled: the interforaminal segment of an edentulous mandible (class V according to Cawood and Howell (17, 18)), cylinder segments of the peri-implant bone, 4 titanic dental implant abutments in the perpendicular position to the occlusal plane, 14-tooth solid screw-retained bridge made of cobalt-chrome alloy and 4 fixation screws made of cobalt-chrome alloy (Fig. 1). The length of the superstructure was selected so as to be equivalent to that used in a clinical situation. The cortical bone tissue was modeled to match the bone type D1, according to the classification by Lekholm and Zarb, encompassing the spongiosis bone by 2 mm. For research purposes, the Ankylos® (Friadent GmbH, Mannheim) dental implant system was chosen: the implants of 3.5 mm in diameter and 8 mm in length; the abutments of 0.75 mm in height of gums, 5.5 mm in diameter, and 2.4 mm in fixation height; and retaining screws (occlusal hexagon 1.6 mm).

All the materials were considered elastic, homogeneous and isotropic. Young‘s modulus and Poisson‘s ratio defining material properties (Tab. 1) of the system elements were taken from literature sources (19).

Tab.1. Material properties

System element	Material	Young's modulus (GPa)	Poisson's ratio, μ
Segment of an edentulous mandible	bone	10,63	0,313
Peri-implant bone		12,51	0,313
Implant	titan alloy	110	0,30
Abutment			
14-tooth solid bridge	cobalt-chrome alloy	190	0,29
Fixation screw			

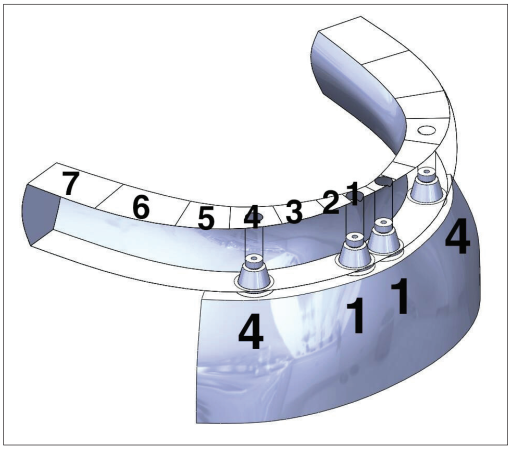

Fig. 2. Dental implants locations in the position of the central incisors [“1”] and the first premolars [“4”]

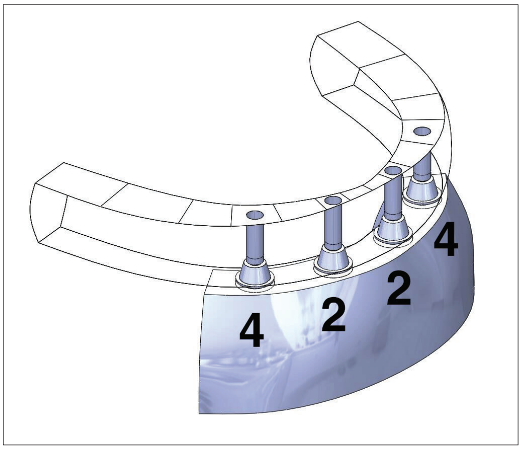

Fig. 4. Dental implants locations in the position of the lateral incisors [“2”] and the first premolars [“4”]

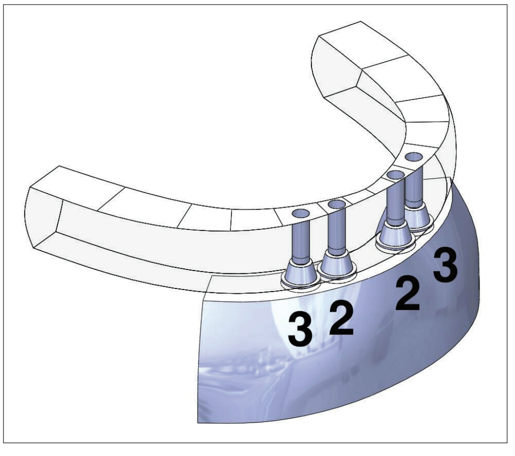

Fig. 3. Dental implants locations in the position of the lateral incisors [“2”] and the canine teeth [“3”]

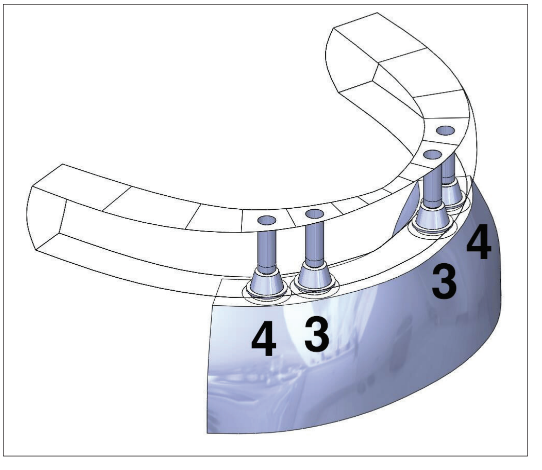

Fig. 5. Dental implants location in the position of the canine teeth [“3”] and the first premolars [“4”]

COSMOS and SolidWorks program packages were used to model the research objects. The system elements were interconnected by a rigid connection in thread joints and bone layer joints and by a no-penetration connection in other places of contact. The model was fixed at the bottom of a mandible segment (20). To imitate the chewing strength a load of 300 N acting perpendicularly on the surface of the prosthesis in the position of all the cantilevers was chosen and recorded changing the position of dental implants with respect to each other (symmetrically in the position of the central incisors [“1”] and the first premolars [“4”], in the position of the lateral incisors [“2”] and [“4”], in the position of the canine teeth [“3”] and [“4”], and in the position of [“2”] and [“3”]) (Fig. 2-5). The changes of stresses in the mandible bone were evaluated according to the numerical values of von-Misses stresses. The form of elements of the model was simplified in order to reduce the time for computer calculation (21).

Results

In the present study, the lowest peri-implant bone stresses around the distal implant were when the implants in the system were arranged according to the 4-2-2-4 scheme. There were insignificant differences in the stresses according to the 4-1-1-4 scheme of implant positioning. The greatest stresses were observed in the 3-2-2-3 scheme and were 1.71 times greater in the regions of distal implants.

The lowest peri-implant bone stresses of central dental implants were recorded when the implants were positioned according to the scheme 3-2-2-3.

In case of the scheme 4-2-2-4, bilaterally peri-implant bone stresses around a distal implant increased by 83% if 10-tooth dental prosthesis was prolonged by 1 molar tooth and by 200% if it was prolonged by 2 teeth; meanwhile, in the scheme 4-1-1-4, the stresses increased by 89% and 212%, respectively; and in the scheme 4-3-3-4 by 95% and 225%, respectively. In the scheme 3-2-2-3, there were more significant changes in the stresses since the cantilever was longer by 1 tooth due to a different position of the distal implant.

In all the analyzed structures the greatest structure-affecting load was on the most distal tooth. In case of a shortened dental arch, the lowest peri-implant bone stresses of the distal implant were in the scheme 4-1-1-4; they were by 2.7% greater in the scheme 4-2-2-4, by 10.1% in the scheme 4-3-3-4, and by 101% greater in the scheme 3-2-2-3.

In the case of a 12-tooth arch, the lowest peri-implant stresses around the distal implant were in the scheme 4-2-2-4; they were by 1.1% greater in the scheme 4-1-1-4, by 15.3% greater in the scheme 4-3-3-4 and by 82.1% greater in the scheme 3-2-2-3. It can be stated here that there was no significant difference between the schemes 4-2-2-4 and 4-1-1-4 since the observed 1.1% difference of the stresses can be attributed to the peculiarities of FEM calculation.

In case of a 14-tooth arch the lowest peri-implant stresses around the distal implant were in the scheme 4-2-2-4; they were by 1% greater in the scheme 4-1-1-4, by 16.7% greater in the scheme 4-3-3-4, and by 71% greater in the scheme 3-2-2-3. Like in the case discussed above, no significant difference was observed between the schemes 4-2-2-4 and 4-1-1-4.

In Fig. 6a is shown general view of stress distribution in peri-implant bone and in Fig. 6b and Fig. 6c shown are stresses higher than 12.5 MPa and 8.6 MPa. Colored zones show that in central implants peri-implant bone tension is present and in distal implants – there is compression. Stress is lower than the ultimate strength of peri-implant bone.

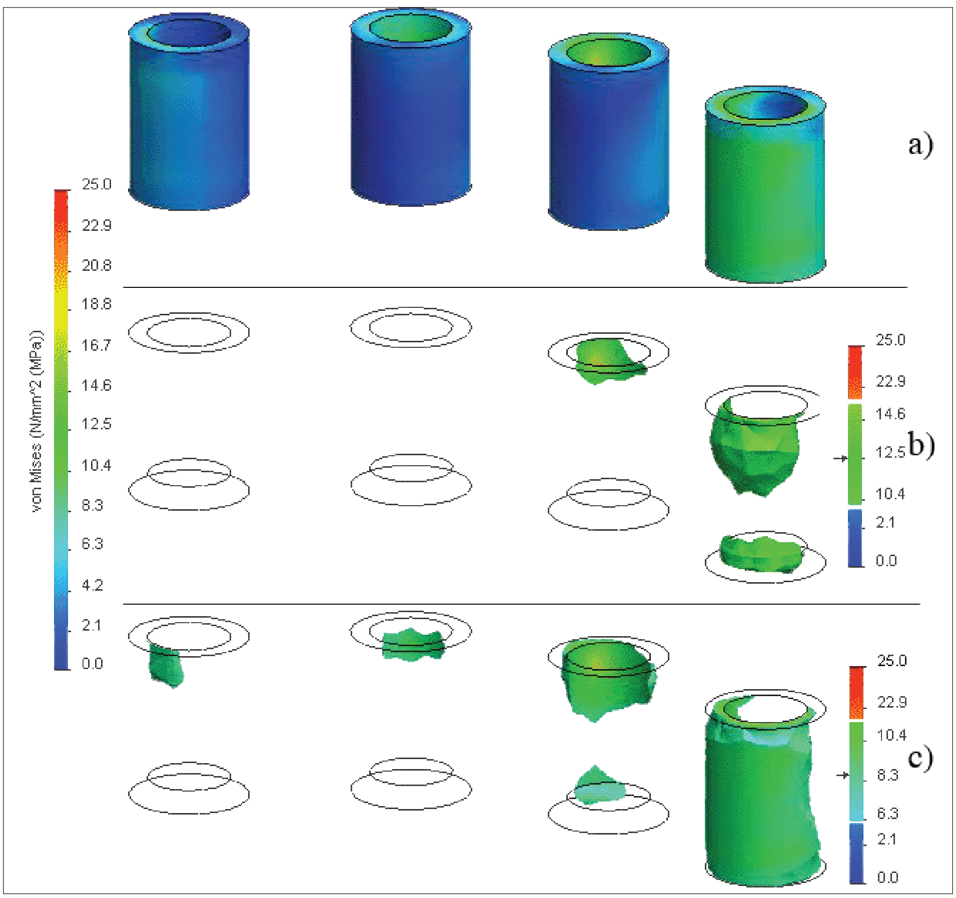

Fig. 6. Views of stress distribution in peri-implant bone around all four implants (scheme 4-2-2-4)

Discussion

Three decades ago, a new concept, known as a shortened dental arch, i.e., from premolars to premolars (10 teeth) (22), appeared in the treatment of older patients; however, it is preferred that the treatment restores a dental arch as naturally as possible (12 or 14 teeth in one mandible) in order to improve the life quality of patients. Due to the atrophy of an alveolar ridge of the mandible, dental implantation without bone grafting's or nerve lateralization surgery is possible only in the interforaminal segment, i.e. distal implants are positioned in the area of the first premolars ["4"]. During the production of dental prosthesis the second premolars and molars (the first and the second) are formed in the cantilever of prosthesis above gums.

After a 3-dimensional system was modeled and simulation load was performed in the area on the occlusal surface of prosthesis, stresses around all the 4 dental implants were measured, i.e. there are no sleeping implants in the concept and during the function they pass the functional load on the peri-implant bone. Like in other similar studies (23), the measured stresses are always greater around distal dental implants in all the analyzed systems with a changing cantilever length and the results are similar to clinical reality, i.e. the failure rate is generally higher for implants in the posterior region than in the anterior (12, 24).

The observed stress changes are normal and can be explained by the principles of material mechanics. According to the form of the mental part of the mandible the anterior-posterior spread of implants in schemes 4-1-1-4 and 4-2-2-4 are almost similar. Therefore the values of the loads on the implants ["1"] and ["2"] are similar too. From the biomechanical point of view, positioning of the central implants closer to the distal implants results in a single abutment phenomen. Thus, the load acting on the distal implants increases. At the same time, the values of the peri-implant bone stresses increase. On the other hand, if the implants are positioned closer to each other the stress superposition principle, i.e. the overlapping of stress fields formed around each implant appears, which also enhances the values of bone stresses.

The evaluation of the recorded changes of the stresses allows stating that it is better to increase the distance between the implants rather than position them in pairs. This also enables a clinician to maintain recommended physiological distances between implants in order to ensure blood circulation in the interimplant bone during osteointegration and allows a patient to maintain proper individual hygiene after a prosthesis procedure.

Such significant changes of the peri-implant bone stresses with prolonged bridge cantilevers allow drawing a conclusion that in case of clinical and X-ray observation of peri-implant marginal bone loss due to potential functional overload the first choice procedure. If the quantity and quality of bone tissue is insufficient, there is the shortening of the cantilever or reduction of the chewing surface on the cantilever or its total refusal (25). Also, implants need to be equally arranged according to the perimeter of a bridge in order to avoid the superposition of stress.

One of the ways to reduce the influence of the cantilever on the peri-implant bone is the angular positioning of a marginal implant which shortens the cantilever (26); however, this also causes changes of stresses on the weaker elements of a structure (abutments and fixation screws).

On the basis of the obtained results, a hypothesis can be raised that overloading can be reduced changing orientation of implants so that middle implants take more loads which act on the bridge and creating inner intra-implant amortization systems.

Conclusions

The full dental arch on four implants concept research showed that stresses were formed around all the 4 dental implants during a functional load on the cantilever. The lowest peri-implant stresses were recorded when the dental implants were positioned according to the 4-2-2-4 and 4-1-1-4 scheme. A shortened cantilever significantly reduced the peri-implant overloading around a distal dental implant, in certain cases reaching 358%.

The authors state no conflict of interest.

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VISO DANTŲ LANKO TILTO ANT KETURIŲ DANTŲ IMPLANTŲ GEMBĖS ILGIO ĮTAKA ĮTEMPIŲ PASISKIRSTYMUI PERIIMPLANTINIAME KAULE

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Raktažodžiai: periimplantinis kaulas, gembė, BEM.

Santrauka

Įvadas ir tyrimo tikslas. Pacientų su bedančiais apatiniais žandikauliais gydymui taikoma keturių dantų implantų su viso dantų lanko tilto fiksacija ant jų taktika. Kelios atliktos studijos parodė gembės ilgio įtaką kaulo įtempiams apie dantų implantus. Tyrimo tikslas – nustatyti tilto, fiksuoto ant keturių dantų implantų, gembės ilgio įtaką įtempių kitimams periimplantiniame kaule.

Tyrimo metodika. Tyrimui pasirinkta trimatė baigtinių elementų tyrimo metodika. Sumodeliuotas trimatis bedančio apatinio žandikaulio modelis su dantų implantais tarpmentaliniame segmente. Pasirinktos keturios dantų implantų pozicijų variacijos bei jie sujungti 14 dantų tiltu. Imituota kramtomoji 300 N jėgos apkrova tilto gembėje. Rezultatai. Mažiausi įtempai kraštinio implanto periimplantiniame kaule, kai dantų implantai žandikaulyje pagal sistemą 4-2-2-4, tik 1% didesni - 4-1-1-4, 16.7% didesni 4-3-3-4 ir 71% didesni sistemoje 3-2-2-3. Didžiausi įtempiai kraštinio implanto ir mažiausi įtempiai centrinio implanto periimplantiniame kaule, kai implantai sistemoje 3-2-2-3. Gembės ilginimas reikšmingai veikia įtempių padidėjimus kraštinio implanto periimplantiniame kaule visose tirtose sistemose.

Išvados. Atliktas tyrimas parodė, kad, imituojant kramtomosios jėgos apkrovą gembėje, įtempiai susiformuoja apie visus dantų implantus. Mažiausi įtempiai kraštinio implanto periimplantiniame kaule, kuomet dantų implatai sistemose 4-2-2-4 ir 4-1-1-4. Gembės ilgio trumpinimas reikšmingai sumažina periimplantinio kaulo įtempius apie kraštinį implantą net iki 358%.

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