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Influence of cantilever length on stress distribution in fixation screws of All-on-4 full-arch bridge

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1. Introduction

Since dental implants were introduced for rehabilitation of the edentulous patients in the late 1960s, the use of implants revolutionized dental treatment modalities and provided good long-term results. The problem of edentulism is topical around the world and the percentage of edentulous people in some age-groups can reach up to 40% [1]. 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 [2]. 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 [3].

"All-on-4" concept was developed to overcome anatomical limitations in the edentulous mandible cases. Treatment is based on four dental implants insertion in the interforaminal segment for supporting a full-arch prosthesis with a maximum of a two-tooth distal cantilevers in molar region bilaterally [4, 5].

Several studies have indicated that fixation screw loosening is a most common mechanical complication of multiple tooth implant restorations [6], because it's the weakest element in implant-abutment-crown construction [7].

Screw-retained restorations offer a rigid connection between the restoration and the abutment. During chewing and biting, the prosthetic restoration is affected by various physiological forces e.g. on a single molar implant might be short force maximum up to an average of 847 N for men and 595 N for women [8].

The chewing load is absorbed and amortized by the periodontal ligament around the dental root, which is impossible in case of dental implant. Thus, occlusal loads directly affect all fixation elements through prosthesis. The small fixation screws that fasten restorations to implants can come loose. The greater micromotion in the joint result failure and loss of implant function [9, 10].

A literature review showed that screw loosening or fracture varied between 2% and 45% of the implant restorations [11]. A meta-analysis on implant-related complications calculated a cumulative incidence of connection-related complications of 7.3% after 5 years of clinical service [12]. The incorporation of cantilevers into implant-borne prostheses was associated with a higher incidence of technical complications related to the supra-constructions (20.3% vs. 9.7% for non-cantilever prostheses) [13]. Many attempts have been made to overcome screw loosening problem by incorporating anti-rotational and other screw design variations [14].

One of the in vitro possibilities to study dental implants is the finite element method (FEM). Due to a universal nature of the research, FEM is a powerful and effective tool for predicting the mechanical behavior of dental restorations, fixed partial dentures and implant supported prostheses. The method consists of a few steps starting with the two-dimensional (2D) and three-dimensional (3D) 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 [15-17].

The aim of the study was to determine the influence of the cantilever length, implants position and occlusal force location on the stress distribution in fixation screws within the framework of the All-on-4 concept using the finite element analysis.

2. Material and methods

For research purposes, 3D form system elements were modeled: the interforaminal segment of an edentulous mandible (class V according to Cawood and Howell [18], cylinder segments of the peri-implant bone, 4 titanic dental implant abutments in the perpendicular position to the occlusal plane, 14-tooth solid bridge with perforations for fixation 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 I, according to the classification by Lekholm and Zarb, encompassing the spongiosis bone by 2 mm. For research purposes, the Ankylos® (Friadent GmbH Mannheim, Germany) dental implant system was chosen: the implants of 3.5 mm in diameter and 11 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).

A load of 300 N was applied to the occlusal surfaces. The maximum von-Misses stress on the fixation screws was measured.

All the materials were considered elastic, homogeneous, and isotropic. Young's modulus and Poisson's ratio defining material properties of the system elements were taken from literature sources [19]. Mechanical properties are given in Table 1.

Table 1

Mechanical properties

Material	*E*, GPa	υ
Peri-implant bone	12.51	0.313
Cortical bone	10.63	0.313
Titan	110	0.3
Cobalt-chrome alloy	211	0.31
Stainless steel	190	0.29

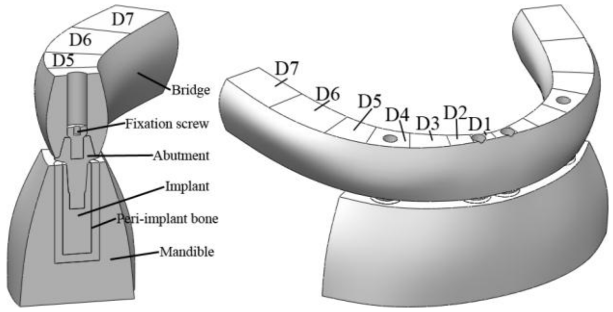

Fig. 1 Scheme of investigated structure

SolidWorks and Simulation 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 D1 and the first premolars D4, in the position of the lateral incisors D2 and D4, in the position of the canine teeth D3 and D4, and in the position of D2 and D3). Adaptive meshing method, high quality mesh and tetrahedral elements with 10 nodes were used.

The changes of stresses in the fixation screws 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].

3. Results and discussions

First, it is necessary to clarify how implant positioning in the mandible influences loads of fixation screws.

It was determined that the highest von-Misses stress concentrates on the marginal fixation screw on the side the load is applied. However, the value of maximal stress and the location where these stresses form vary.

It was determined that stress values did not differ much if the load location changed from 1 to 3 in the systems 4-1-1-4 and 4-2-2-4 (Table 2). This shows that the loads in this case of loading are almost equally distributed on all fixation screws. From the practical implantology perspective, it can be stated that there is no great difference where frontal implants are to be positioned in case of such loading on the All-on-4 system. But when the load is applied on D4, the stress on the fixation screw of this implant increases by about 1.5 times. This shows that the screws of frontal implants are unloaded. The difference of stress on fixation screw D4 between the systems 4-1-1-4 and 4-2-2-4 increases up to 8.7%.

Table 2

Comparison of 4-1-1-4 and 4-2-2-4 systems

Compared Systems	D1	D2	D3	D4	D5	D6	D7
4-1-1-4 and 4-2-2-4	0.45%	7.43%	1.59%	8.65%	97.86%	48.36%	12.42%

A tendency was observed that the location factor of central implants emerges in cases the load is applied on D5 or further teeth. Greater stresses are formed in 4-1-1-4 than in 4-2-2-4. It is an interesting fact that the greatest difference appears when the load is applied on D5. When the load location changes from D4 to the end of the cantilever, the difference decreases. Certainly, the stress values increase due to an increasing bending moment. On the basis of the calculated stress values, it is possible to state that when the load is applied on D5 and further teeth of the cantilever small plastic deformations are formed in the local zones of fixation screw D4, which can influence the formation of little backlash in the screw connection.

Such worse treatment of the system 4-1-1-4 in comparison with 4-2-2-4 can be explained as follows: when frontal implants are close to each other in the mandible with such geometry, the All-on-4 concept acts like the All-on-3 concept; therefore, screw bending to the outside of the mandible increases and system stability decreases.

A comparison of the above mentioned systems with the system 4-3-3-4 demonstrated that the latter was much worse (Table 3). The calculations have confirmed that such a system is not acceptable for practical usage because the system works like All-on-2. Such a system is not stable. When a patient bites and later chews food, the location of the load changes from D1 to D7, which conditions fast cyclic fatigue of screws.

Table 3

Comparison of systems 4-1-1-4 and 4-2-2-4 with system 4-3-3-4

Compared Systems	D1	D2	D3	D4	D5	D6	D7
4-1-1-4 and 4-3-3-4	57.85%	66.83%	29.63%	10.95%	61.81%	13.67%	16.77%
4-2-2-4 and 4-3-3-4	58.56%	55.30%	27.60%	2.12%	22.28%	30.52%	31.26%

Another important aspect in the practice of implantologists is to know how the location of load applying influences elements of the All-on-4 system, for example, fixation screws as in the present analysis.

As it can be seen in Table 4, rude change is obtained when the load is applied on the first tooth after the marginal implant. The load applying further to the end of the cantilever does not significantly influence the gradient of the stress increase. However, as it can be seen in Fig. 1, the longer the cantilever is, the faster the stress increases. The system 4-2-2-4 is the least sensitive to an increasing cantilever length. It can be explained by a few facts. The comparison of this system with 4-1-1-4 demonstrates that the distance from D4 to the central implants does not differ significantly; however, in the system 4-2-2-4, central implants are more distant from each other, which results in greater stability of the system and less significant screw bending into the outside of the mandible. This screw loading component is greater in the system 4-1-1-4. The hypothesis is dominant until the cantilever is as long as 1 or 2 teeth. When the length of the cantilever is 3 teeth, the outer bending component becomes less important, and the vertical bending component becomes more important. Because the distance between D1 and D2 is not great, the difference between vertical bending moments in the systems 4-1-1-4 and 4-2-2-4 is not significant. On the other hand, it is possible that the system 4-2-2-4 is more “mobile” than 4-1-1-4. Therefore, the screws of other implants absorb the load.

Table 4

Comparison of systems

Load applying place	4-1-1-4		4-2-2-4		4-3-3-4		3-2-2-3	
D1	10.40%	-	2.30%	-	4.45%	-	57.52%	-
D2		6.88%		13.02%		37.55%		53.93%
D3	66.1%		50.52%		15.51%		121.90%	
D4		253.50%		94.12%		142.40%		83.39%
D5	42.3%		89.84%		102.62%		78.57%	
D6		27.22%		67.89%		68.85%		56.30%
D7	-		-		-		-	

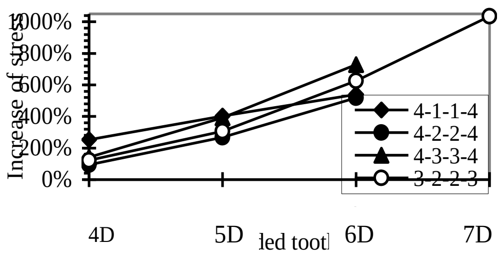

Fig. 2 Stress change dynamic’s relation due to cantilever length in case the load is applied on the rearmost tooth

If the systems where central and marginal implants are close to each other are compared, it can be observed (Fig. 2) that the influence of load is absolutely similar in its dynamics. It can be associated with the fact that in both systems 4-3-3-4 and 3-2-2-3 bending dominates and its load is almost the same on the neighboring screws. The difference of the values between analogous cantilevers appears because of a different distance between neighboring teeth, i.e., between 2 and 3 and between 3 and 4. Because of human physiology, the distance between 3 and 4 is bigger. On the basis of accomplished calculations, it can be stated that these systems with the cantilevers as long as 1 or 2 teeth could compete with the system 4-1-1-4. But the cantilevers which are as long as 3 teeth are much worse.

One difference between 3-2-2-3 and other systems was observed. Stress minimal value in screw D4 was determined when the load was applied on D1. When the load location was changed from D1 to D7, the stress values on screw D4 increased. Meanwhile, in other systems, the stress minimum was observed when the load location was on D2. On the other hand, this decrease was not great. Therefore, authors associate it with the peculiarity of FEM.

4. Conclusions

1. From the point of view of screw stressing, implantologists who use the All-on-4 concept should position implants in the places of the second and the fourth tooth.

2. If it is not possible to use the system 4-2-2-4, the system 4-1-1-4 can be used, too.

3. The cantilever length should not exceed 3 teeth.

4. The systems with neighboring implants are undesirable. Such systems are not enough unstable. The screws obtain marked loads. During food chewing, cyclic bending can affect screw fracture.

5. The cantilever length should not exceed 2 teeth for the system 4-1-1-4, 3 teeth for the system 4-2-2-4, 2 teeth for the system 4-3-3-4, and 2 teeth for the system 3-2-2-3.

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GEMBĖS ILGIO ĮTAKA VISO DANTŲ LANKO PROTEZO FIKSAVIMO VARŽTELIUOSE „ALL-ON-4" SUSIDARANČIŲ ĮTEMPIŲ POKYČIAMS

R e z i u m ė

Bedančiams pacientams gydyti vis dažniau taikoma All-on-4 koncepcija, paremta viso apatinio žandikaulio dantų lanko protezavimui naudojant keturis dantų implantus. Kadangi konstrukcijoje naudojamos abipusės gembės, kurių ilgis nėra standartizuotas, susiduriama su mechaninėmis techninėmis komplikacijomis – fiksaciniai protezo varžteliai atsisuka arba lūžta.

Šiame straipsnyje analizuojami skaitiniu metodu gauti sistemos varžtuose susidarančių įtempių pokyčiai, kintant implantų ir apkrovos padėtims, taip pat tiltinio protezo gembinės dalies ilgiui. Straipsnyje nagrinėjama, kaip ir kiek minėti veiksniai sąlygoja fiksaciniuose varžtuose susidarančius įtempius. Gauti rezultatai rodo, kad implantologai turėtų vengti sukti implantus arti vienas kito ir nenaudoti ilgesnių negu trijų dantų gembių. Palankiausias implantų išdėstymas yra 4-2-2-4.

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INFLUENCE OF CANTILEVER LENGTH ON STRESS DISTRIBUTION IN FIXATION SCREWS OF ALL-ON-4 FULL-ARCH BRIDGE

S u m m a r y

The All-on-4 concept is a useful therapy in the treatment of an edentulous mandible. Just few studies have shown the effect of the cantilever length on fixation elements. The aim of the study was to clarify the influence of the cantilever length and implant position relating with load position on the stress and their distribution in fixation screws in the framework of the All-on-4 concept.

There were analyzed how and in what degree the mentioned factors influence dynamics of change of stress in fixation screws. The results show that implantologists would not turn implants close each other and do not use cantilevers as long as three teeth. The most advantageous implant positioning is 4-2-2-4.

The worst case is when implants locate near each other (case 3-2-2-3). Two nearby implants act as one. Therefore screws receive greater loads.

Keywords: edentulism treatment; finite element method; All-on-4 concept; fixation screw loosening; cantilever length.

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