Biomechanics of self-loosening of the screw that connects the intraosseous part of the implant and the abutment with the orthopedic structure attached to it

Ye Semenov\(^1\) and M Surianinov\(^2\)*

\(^1\)State Establishment «The Institute of Stomatology and Maxillo-Facial Surgery National, Academy of Medical Science of Ukraine», Rishelevskaya str., 11, Odessa, 65026, Ukraine
\(^2\)Odesa State Academy of Civil Engineering and Architecture, 4, Didrihsona str., Odesa 65029, Ukraine

*E-mail: sng@ogasa.org.ua

Abstract. The results of the study of the stress-strain state in the elements of the system “intraosseous part of the implant - screw - abutment with an orthopedic structure fixed on it” under different given conditions of its functioning are presented. We have determined the stress-strain state in the crown neck area, which replaces the upper jaw central incisor, in the presence of the natural wear (0.5 mm) of the teeth and anthropoid teeth next to the implants and the same nine load variants as in the initial non-prosthetic model, i.e. a total of 54 calculation experiments have been carried out. It has been established that the occurrence of such secondary mechanical complication of dental implantation as loosening of the screw connection between the intraosseous part of the implant and the prosthetic structure fixed on the abutment influences the type of teeth clamping (bite), the angle of the preferential transfer of chewing load, the propensity and the wear ability of the teeth. The most unfavourable, in terms of the value of the torque that unwinds the fixation screw, is the direct occlusion of the teeth and the angle of the preferential load transfer of 145° (\(M_{pr} = 1.16\) Nm), or 3.87% of the twisting torque value. At the same conclusions of the set parameters and the value of erosion of its teeth 0.5 mm the value of the torque, which untwists, increases by 5 times and corresponds to 19.3% of the initial torque (30 Nm) and will inevitably lead to its untwisting.

1. Introduction
One of the serious problems encountered by orthopedic surgeons during the prosthetics of patients with two-stage cylindrical implants supporting fixed prosthetic structures is self-loosening of the screw that connects the intraosseous part of the implant and the abutment with the prosthetic structure fixed to it. Clinical studies have shown that this complication is diagnosed in 13% of patients. The average service life of an orthopedic structure before the onset of the above complication was 8.1±2.4 years (at the time of delivery, the connecting screw was tightened with a force of 30 Nm, which is recommended by most implant manufacturers).

Based on the examination of 53 patients with this type of complication, we found that hyperocclusion foci were detected in 100% of cases in the area of problematic prostheses, which was a result of changes in the maxillofacial apparatus some time after their placement. This was supported by the fact that there were no hyperocclusion foci in the area of the problematic constructs at the time of delivery of the orthopedic device. In 79.2% of the patients with the studied types of complications, they were single crowns or bridges within the same functionally oriented group [13, 14].

Thus, on the basis of the above, we can conclude that studying the biomechanics of functioning of the system intraosseous part of the implant - screw, connecting it to the superstructure, in changing conditions of its functioning on the basis of mathematical modeling is a topical task of modern dentistry. At the same time, it should be noted that in terms of mathematical analysis it is a complex applied problem, since the constituent materials of the model (implant, connecting screw, cancellous
bone, cortical bone, dentin) have different physical and mechanical properties, and the model functioning conditions are characterized by significant variability.

2. Recent researches analysis
Recently, the use of two-stage cylindrical screw implants as a support for fixed orthopedic structures has become increasingly widespread [1, 2]. However, the number of prosthetic complications during the long-term functioning of fixed orthopedic constructions based on this type of implants is also increasing [3-5]. One of the most serious complications is the loosening of the screw that connects the intraosseous part of the implant and abutment with the fixed prosthetic structure fixed to it [8]. According to our data, the frequency of this complication is 6.3% of the total number of implants placed [3]. It is associated with changes in the dentoalveolar system that occur over time, and lead to tooth erosion or formation of traumatic occlusion nodules with changes in periodontal tissues, and, as a consequence, an increase in the load on the screw that connects the intraosseous part of the implant and abutment with fixed prosthetic structure fixed to it [6, 7].

3. The purpose of this work is to study the stress-strain state in each element of the system “intraosseous part of the implant - screw - abutment with an orthopedic structure fixed on it” under different given conditions of its functioning.

4. Materials and methods
Modern biomechanical studies are based on detailed computer modeling of objects, which allows performing comprehensive computational experiments in high-performance software packages. The vast majority of these complexes are based on the use of a numerical calculation method - the finite element method (FEM) [9, 10]. This approach makes it possible to build models of any geometric complexity with high accuracy and to determine the stress-strain state of an object at all its points, which is ideal for studying the biomechanics of both the entire dentoalveolar system and its individual parts. In our case it is a fragment of the frontal area of the upper jaw with a two-stage cylindrical screw implant embedded in it, with a fixed orthopedic structure fixed on it, replacing the central incisor. All constructions and calculations were performed using the ANSYS software package [11].

5. Research results
In the process of work to achieve the goal, the following tasks were solved:
- a three-dimensional finite-element model of an upper jaw segment with four frontal teeth, including dentin volume, cortical and cancellous bone with subsequent replacement of the central incisor with an artificial crown, supported by an intraosseous two-stage cylindrical implant (Figure 1) was built;
- the stress-strain state in the upper jaw central incisor neck area at different tooth closing angles (125°, 135°, 145°), force application point corresponding to direct, normognathic, deep teeth overlapping, the given value of 0.5 mm tooth wearability (here the value of the central incisor wearability, simulating an artificial crown supported by a dental implant, is taken as equal to zero);
- the character of tangential stress $\tau_{xy}$ (one of the components of the total stress in the area of the tooth neck under given conditions), creating a torque that leads to the loosening of the screw that connects the intraosseous part of the implant and the superstructure, was studied.

The method of constructing a finite-element model, which was subjected to a multidimensional computer analysis, was described by us earlier [7, 8].
During the study of the built model the stress-strain state in the upper jaw central incisor neck area was studied, as the value of these stresses affects the value of the torque of the screw that connects the implant to the abutment. It should be noted that at the stage of preliminary studies it was established that the value of tension in the area of the tooth neck of the central incisor of the upper jaw and the value of tension in the area of the neck of the artificial crown fixed on the abutment of the two-stage cylindrical implant replacing the central incisor of the upper jaw are comparable.

We considered three variants of teeth occlusion, which corresponded to normognathic, deep and straight bite at different angles of load transfer (125°, 135°, 145°). Also in our previous studies we have studied the stress-strain state in the maxillary central incisor tooth neck at angles of load transfer (125°, 135°, 145°) with a given value of natural tooth and antagonist teeth erosion, equal to 0.5 mm; and the value of erasability of the metal-ceramic crown, fixed on the central incisor of the upper jaw, we neglected, since it is subject to much less erosion than natural teeth [7].

The model in question was exported to SolidWorks [12] for ease of simulation of erosion. As an example, Figure 2 shows the stress fields at direct occlusion at angles 1350 and 1450 and the erasability of adjacent teeth and antagonist teeth of 0.5 mm.

![Figure 1. Fragment of a model of the dentoalveolar system.](image)

**Figure 1.** Fragment of a model of the dentoalveolar system.

![Figure 2. Stress fields at 135o and 145o straight occlusion and 0.5 mm abrasion of adjacent and antagonist teeth.](image)

**Figure 2.** Stress fields at 1350 and 1450 straight occlusion and 0.5 mm abrasion of adjacent and antagonist teeth.
The results obtained served as the basis for the next stage of the computational experiment. The frontal incisor of the maxilla was removed from the model and replaced with a two-stage screw implant of the LIKo system with an artificial crown fixed to it. From the possible modifications of the geometric sizes of the implants (Table 1), six were chosen for the study: 1.101, 1.102, 1.201, 1.202, 1.301, 1.302.

| №  | Length, mm | Diameter, mm | Modifications |
|----|------------|--------------|---------------|
| 1.101 | 8           |              |               |
| 1.102 | 10          | 3.5          |               |
| 1.103 | 13          |              |               |
| 1.104 | 16          |              |               |
| 1.201 | 8           |              |               |
| 1.202 | 10          | 4.0          |               |
| 1.203 | 13          |              |               |
| 1.204 | 16          |              |               |
| 1.301 | 8           |              |               |
| 1.302 | 10          | 5.0          |               |
| 1.303 | 13          |              |               |

Thus, the experiments varied the implant diameter (three sizes) with two lengths of each implant.

6. Research results and discussion

In the course of the work we determined the stress-strain state in the neck area of the crown replacing the central incisor of the upper jaw in the presence of natural abrasion (0.5 mm) of the adjacent teeth and antagonist teeth for each of the six implant sizes under study and the same nine load variants as for the initial non-prosthetic model, that is, a total of 54 calculation experiments were performed.

Table 2 shows the results of calculations of the model fragment with implant No. 1.202. As it should be expected, the stresses and strains in the components of the maxillary system, excluding, of course, the implantation zones, in all 54 experiments practically do not differ from each other, i.e. do not depend on the geometrical parameters of the implants.

As for the stresses in the implants themselves, of course, they depend significantly on their geometry, but in all cases they are much lower than the allowable stresses, i.e. there is a significant safety margin.
The dentoalveolar system in which an orthopedic structure supported by dental implants is built is not static, the changing conditions of its functioning (wearability of its teeth) contribute to the occurrence of such a secondary mechanical complication of dental implantation as loosening of the screw connection between the intraosseous part of the implant and the superstructure. Based on these findings, we recommend the fabrication of fixed orthopedic structures with dental implants with pre-planned access to the fixation screw.

According to the results of the conducted numerical experiment with the help of the ANSYS finite-element software and the constructed three-dimensional computer model, it was established that the occurrence of such secondary mechanical complication of dental implantation as loosening of the screw connection between the intrabone implant part and the prosthetic structure fixed on the abutment is affected by the type of teeth occlusion (bite), the angle of preferential transfer of chewing load, propensity and erasibility of their teeth. The most unfavourable, in terms of the value of the torque that unscrews the fixation screw, is the direct occlusion of the teeth and the angle of preferential load transfer of 1450 (Mpr = 1.16 Nm), or 3.87 % of the twisting torque value. With the same conclusions of the set parameters and the value of abrasion of its teeth 0.5 mm the value of torque, which untwists, increases by 5 times and corresponds to 19.3 % of the initial torque (30 Nm) and will inevitably lead to its untwisting.

| Clamping type         | Angle, deg. | Stresses, MPa | Deformation |
|-----------------------|-------------|---------------|-------------|
|                       |             | σ   | τ_{xy} | τ_{xz} | τ_{yz} |              |
| Direct                | 125         | 102.88 | 12.9  | 2.9    | 38.6   | 9.247·10^{-3} |
|                       | 135         | 206.6  | 7.5   | 10.5   | 37.0   | 2.098·10^{-2} |
|                       | 145         | 320.0  | 36.9  | 76.7   | 68.0   | 5.276·10^{-2} |
|                       | 125         | 160.3  | 20.1  | 4.5    | 59.8   | 1.015·10^{-1} |
| Normognathic          | 135         | 154.0  | 5.6   | 7.9    | 26.8   | 8.383·10^{-2} |
|                       | 145         | 140.2  | 15.8  | 32.9   | 28.9   | 6.365·10^{-2} |
|                       | 125         | 122.38 | 15.3  | 3.45   | 41.92  | 6.27·10^{-2}  |
| Deep overlap          | 135         | 119.45 | 4.34  | 6.1    | 21.4   | 4.872·10^{-2} |
|                       | 145         | 117.12 | 13.5  | 28.1   | 24.9   | 3.351·10^{-2} |

Thus, for implant No. 1.101 (minimal geometric dimensions) the highest stresses in the series of experiments were σ_{max} = 202.4 MPa, which is 1.6 times lower than the allowable stresses.

Calculations have also shown that the presence of natural tooth erosion leads not only to an increase in normal stresses, which are mainly responsible for the strength of the structure, but also to an increase in tangential stresses in all three coordinate planes. Of greatest interest are the tangential stresses τ_{xy} in the plane perpendicular to the fixation screw, which generate the torque that ultimately leads to its unscrewing (Table 2). The tangential stresses τ_{xz} and τ_{yz}, occur in the other two coordinate planes and therefore have nothing to do with unwinding. For the maximum tangential stresses τ_{xy}^{max} = 36.9 MPa given in Table 2, the corresponding torque (diameter of the fixing screw d_{Φ} = 2.0 mm) was M_{sp} = 5.79 N·m, which is about 20 % of the initial torque and inevitably leads to self-loosening of the fixing screw.

Assuming that the torque is directly proportional to the tangential stresses τ_{xy}, it is possible, using Table 2, to estimate the torque for each of the 3 types of clamping and each load transfer angle. Obviously, in these cases the torque will be less, but it will be, and so self-torquing of the screw will inevitably occur.

7. Conclusions
The dentoalveolar system in which an orthopedic structure supported by dental implants is built is not static, the changing conditions of its functioning (wearability of its teeth) contribute to the occurrence of such a secondary mechanical complication of dental implantation as loosening of the screw connection between the intraosseous part of the implant and the superstructure. Based on these findings, we recommend the fabrication of fixed orthopedic structures with dental implants with pre-planned access to the fixation screw.
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