BÁNKI KÖZLEMÉNYEK
2. ÉVFOLYAM 1. SZÁM

Geometric design of sleeve and abutment for subperiosteal implants using finite element analysis

Subperiostealis implantátumokhoz persely és abutment geometriai kialakítása végeselem analízis segítségével

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***Abstract* — Nowadays, we experience a rapid development in the field of implantology. Dental implant insertion became a routine procedure during which, mostly screw-type implants are used. Achievements in modern implantology result in such tooth replacements which are perfectly identical to natural teeth both aesthetically and functionally. Thus, chewing ability can be completely restored. The most important advantage of these procedures is that they prevent further bone resorption in neighbouring tissues. The use of custom-made implants becomes even more widespread in modern implantology. Thanks to the patient-specific design, various dental replacements are made that fulfil different needs and expectations of each patient. The creation of these custom design implants is carried out with additive manufacturing technology. This additive technology provides an opportunity for patients who have insufficient bone tissue for the insertion of conical implants. This study presents denture-supporting abutments of different geometric designs. The abutment is directly connected to the sleeve, which is fixed to the subperiosteal implant with micro-welding technology. In geometric design, the distribution of axial forces resultant from the denture is of vital importance as stress levels should be decreased. Examinations were carried out with finite element analysis, which is a widely-used method in engineering practice. By the end of this study, optimal geometric design is determined by comparing the result of each design. The chosen geometry is then implemented into practice and used for the implantation procedure. The material of choice for the subperiosteal implant is Grade 23 titanium alloy, and it is created with an additive manufacturing process. The material of the sleeve and abutment is Grade 5 titanium alloy, and these parts are manufactured with a subtractive process.**

Keywords: implant, subperiosteal implant, finite element analysis, sleeve, abutment

***Összefoglalás* — Napjainkban az implantológia területén robbanásszerű fejlődést tapasztalhatunk. Rutinfeladatnak számít az implantátumok behelyezése, melyekre a legelterjedtebben a csavarimplantátumokat alkalmazzák. Az implantáció segítségével olyan fogpótlásokat készítenek, amelyek esztétikailag és funkcionálisan az eredeti fogakkal teljesen megegyeznek, ezáltal visszaállítják a teljes rágóképességet. Ezen beavatkozások legfontosabb előnye, hogy megakadályozzák a foghiányos csontszövet további leépülését. A modern implantológiában egyre elterjedtebbé válik az egyedi implantátumok alkalmazása. Az individuális tervezésnek köszönhetően a páciens igényeinek, elvárásainak megfelelően készülnek a különböző pótlások. Az egyénre szabott implantátumok gyártása additív gyártástechnológiával történik. Ezen technológia alkalmazása lehetőséget nyújt azon páciensek számára, akiknek nincs elegendő csonttömege a körszimmetrikus implantátumok beültetéséhez. Tanulmányunkban különböző kialakítású abutment geometriákat mutatunk be, melyekre a fogmű fog felfeküdni. Az abutment közvetlenül a perselyhez csatlakozik, ami a subperiostealis implantátumhoz mikro hegesztéssel van rögzítve. A geometriai kialakításnál fontos a fogműről ható tengelyirányú erők eloszlása mivel az ébredő feszültségek csökkennek. A vizsgálatokat végeselem analízissel végeztük, amely eljárás egy elterjedt módszer a műszaki gyakorlatban. A tanulmány végén kapott eredményeket összehasonlítva megállapítjuk a legmegfelelőbb geometriai kialakítást, amelyet alkalmazni fogunk a gyakorlatban, illetve a beültetés során. A subperiostealis implantátum alapanyaga Grade 23-as titánötvözet, melyet additív gyártástechnológiával valósítunk meg. A persely és az abutment Grade 5-ös titánötvözetből készül és szubtraktív eljárással készül.**

Kulcsszavak: implantátum, subperiostealis implantátum, véges elem analízis, persely, abutment

1 INTRODUCTION

The beginning of dentistry dates back to 2000 b.c. Historical sources in cuneiform writing mention toothache from that time. Those days, however, it was thought that these conditions were caused by little wormlike animals. Replacements for lost teeth, made from mainly stones or bones, were used even in ancient Egypt [1, 2]. Implantation as a possibility for tooth replacement was first mentioned by Pierre Fauchard in his book "Le chirurgien dentiste". Maggiolo Manuel attempted to insert golden implants in 1809, although failed to achieve any success with his method. Harris, a dental professional, reattempted the operation in 1887, but he used platinum implants that time [3]. Dr. Edmunds was the first dentist to implant a platinum disc covered by a ceramic crown. Stroc and later Fomiggini created the predecessors of today-known screw-shaped dental implants that were actually used in patients.

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Bränemark, who laid down the basics of osseointegration, is known to be the founder of modern-day implantology. He conducted experiments with screw-type, pure titanium implants in the beginning of the 1950s. His studies showed that bone tissue was able to attach to titanium surface. Moreover, this behaviour was not observed on any other implanted materials [1]. Medical instruments such as dental implants must fulfil strict requirements. Numerous regulations and standards apply to dental implants regarding implant material, instrument, packaging, sterilization, animal tests, technical documentation, and fatigue testing [4]. Subperiosteal implant was invented by Dahl in 1936. The basic principles of subperiosteal implant insertion were the surgical exploration of the jawbone, which served as a basis for cast impression. Implant frame was designed using the impression, which had covered the jawbone. After the surgical re-exploration of the jaw, the completed subperiosteal implant was inserted. The final denture was placed on protruding posts after mucosal healing [1, 5].

2 MATERIALS AND METHODS

Commercially pure titanium and titanium alloys are widely used in different medical applications. Their corrosion resistance and outstanding mechanical properties are among their most notable characteristics. They have high fatigue strength and can withstand high mechanical loads. These properties are highly advantageous for prostheses in dental technician practice. Titanium is quite a ductile material as well. It can also integrate into human tissues due to its osseoconductive properties [6]. The most widely-used titanium alloy in dental technical practice is Ti-6Al-4V, from which Grade 5 alloy is used for metal cutting processes and Grade 23 for additive technologies. It is a dual-phase $\alpha + \beta$ titanium alloy. Aluminium acts as an alpha-stabilizer, while Vanadium stabilizes the beta-phase. The main characteristics of Ti-6Al-4V alloy are the following: good corrosion resistance, low density, high strength-mass ratio, low modulus of elasticity, low coefficient of heat expansion, non-magnetic behaviour, good fatigue resistance, and good mechanical properties at room temperature [7]. Table 1 contains the main mechanical characteristics of Ti-6Al-4V alloy.

Table 1: Mechanical properties of Ti-6Al-4V titanium alloy

Mechanical property	
Elastic limit	950 MPa
Tensile strength	1020 MPa
Elongation	14 %
Contraction	40 %
Rockwell hardness	33 HRC
Modulus of elasticity	120 GPa
Poisson-ratio	0,37

3 NUMERICAL ANALYSIS IN DENTAL IMPLANT

Screw loosening causes one of the major problems in dental implant systems. To avoid this, preloaded screws are used. Implant fracture can occur if the screw is overloaded during its preload. Screw fracture can also arise from occlusal forces. One cause of screw loosening is the eccentric connection resultant from mechanical loads. Load distribution and material fatigue are possible causes of loosening and these mechanisms can potentially decrease the effect of screw preload. Different studies have already showed that the torque for implant tightening recommended by the manufacturer and the preload remain way under the elastic limit of the material. More experimental data is required to confirm the existence of stress relaxation in implant materials. Vibration and damping behaviour is another possible factor that can lead to screw loosening. No reports or studies proved that this dynamic behaviour nearby the implants in the jawbone is a critical factor affecting screw loosening [8].

4 THE MECHANICS OF CONICAL INTERFERENCE FIT IN DENTAL IMPLANTS

The connection between the implant and abutment (superstructure) is determined by screw preload arising from the previously-defined insertion torque. Conical fit leads to high contact pressure that results in high friction resistance. It is important to consider the safety of implant-abutment connection in such fitting compositions. A simplified abutment diagram is shown is Fig. 1 with the axial force resulting from biting [8].

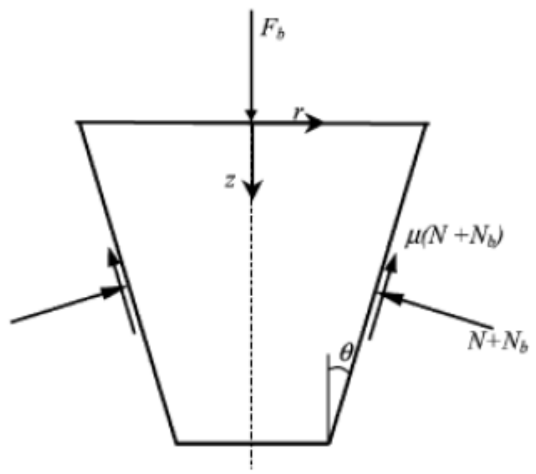

Figure 1: Simplified abutment with the axial forces present

Occlusal forces exerted on the abutment help keeping the connection secure. The mechanism of conical interference fit becomes loose due to the tension force and loosening torque. *Brunski et al.* proved that axial tension load can promote the restoration of multi-phase implants, thus an adequately large tension force is required for the long-term stability at the implant-abutment connection [8, 9].

5 EFFECTS OF BONE TISSUE ON THE PRESSURE AROUND IMPLANT – ABUTMENT INTERFACE

Clinical studies reported bone resorption in implant-surrounding bone tissue. In the following, we assume that the material properties of bone tissue that entirely encapsulates the implant are constant, isotropic, and bone is not osteoporotic [8, 9].

5.1 Classification of interfaces

Interfaces can be classified as the following according to the position of surfaces relative to each other:

- Frictional: surfaces can slide and separate from each other against frictional forces. In this case, friction coefficient must be defined during the examination. In this event, the two parts slide past each other.

- Frictionless: interacting surfaces can easily slide past each other without any friction and energy loss. This case, constraints and load definitions require particular attention to avoid infinite displacement due to frictionless sliding.
- No separation: interacting surfaces cannot separate from each other. However, they can smoothly slide past each other.
- Rough: interacting surfaces cannot slide past one another as friction coefficient is considered infinite. Although they are separable in the direction normal to the interface.
- Bonded: also called welded joint because surfaces cannot move in any direction relative to each other as friction coefficient is considered infinite [10].

Subperiosteal implants: Dahl's procedure had several disadvantages for example, subperiosteal implants did not integrate into the bone tissue, only connective gum tissue kept the implant systems in place. The large number of necessary surgical interventions was also challenging [11].

6 Effects of bone tissue on the pressure around implant – abutment interface

The patient's jawbone is created in a computer-aided virtual design space using the received CB-CT (Cone Beam CT) images and considering medical aspects as well. CT processing is presented in Fig. 2.

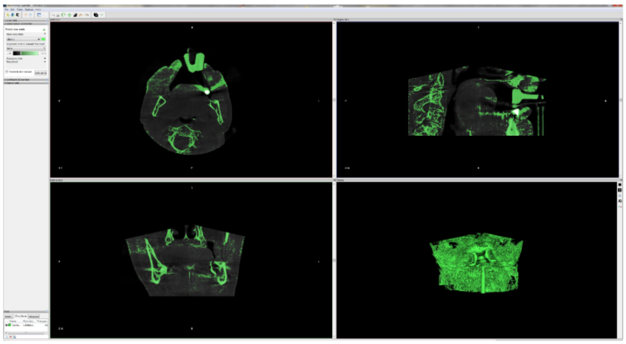

Figure 2: CT processing

The first step of the design process is jawbone surface generation, during which CB-CT images are converted to three-dimensional STL format, which is compatible with different softwares. Images from this process are presented in Fig. 3. Design is influenced by the recommendations of the dental surgeon conducting the operation. The position of future dental implants, dental arch, arrangement, and articulation are planned based on CB-CT images. The ideal position of fixation pillars on the implant is determined by denture geometry. The completed virtual model is then 3D-printed from polymeric material. Further process steps are implemented using this jawbone model.

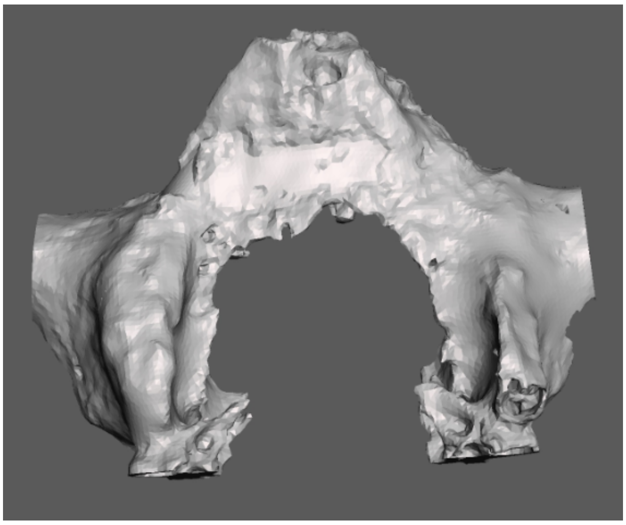

Figure 3: Retrieved bone surface, STL file

7 Single-phase implants

The equations have to be centered and numbered, in case of references. Put the reference numbers between brackets and align to the right margin

7.1 Manufacturing and characterization of single-phase

At first, subperiosteal implants were casted from titanium material. Precision casting was carried out with a vacuum pressure casting machine. Our titanium casts, as shown in Fig. 4, always had to be subjected to X-ray Computer Tomography. Internal voids had to be analysed and dislocations had to be screened. Extensive internal voids were repaired with laser welding, then the workpiece was subjected to another X-ray CT scan. After reaching the desired material homogeneity, fixation pins were removed, and the workpiece went through proper surface treatment. A surface treatment with micro-ceramic particles was used to promote implant osseointegration.

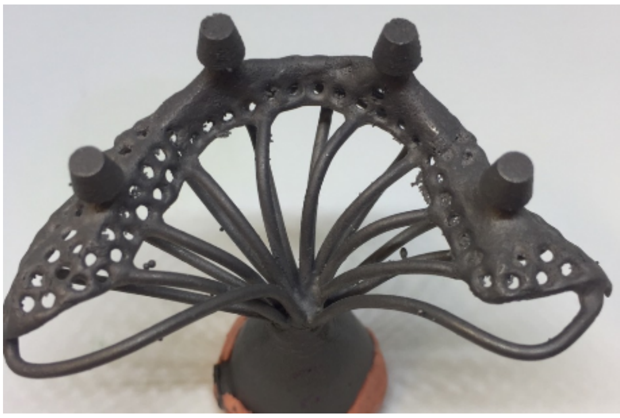

Figure 4: Single-phase cast subperiosteal

One of the disadvantages of single-phase subperiosteal implant was the possible damage of the protruding fixation posts, which would have meant the replacement of the whole implant system. To avoid this, the whole method and the subperiosteal implant construction were completely revised. The single-phase implant was replaced by a dual-phase implant system.

7.2 Dual-phase implant system

Our purpose was to transform the single-phase implant system into a dual-phase one in order to eliminate problems mentioned before. The first version is visible in Fig. 5.

Figure 5: Cast subperiosteal implant

The subperiosteal implant was produced with casting technology and a connecting insert was designed that was fixing the abutment. This solution provided a conical connection geometry with a 3D diagram shown in Fig. 6.

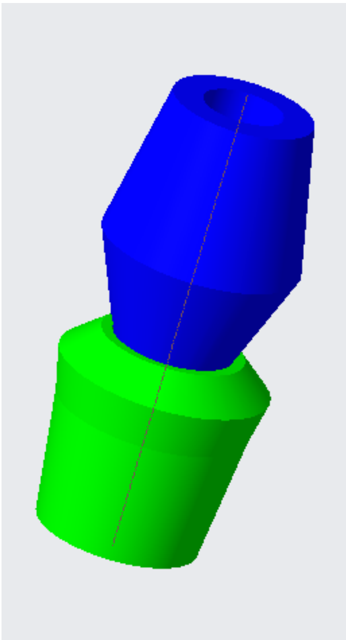

Figure 6: 3D model of internal conical connection

Fig. 7 shows the dimensions of the abutment and sleeve. These parts were machined from Grade 5 titanium alloy (Ti-6Al-4V).

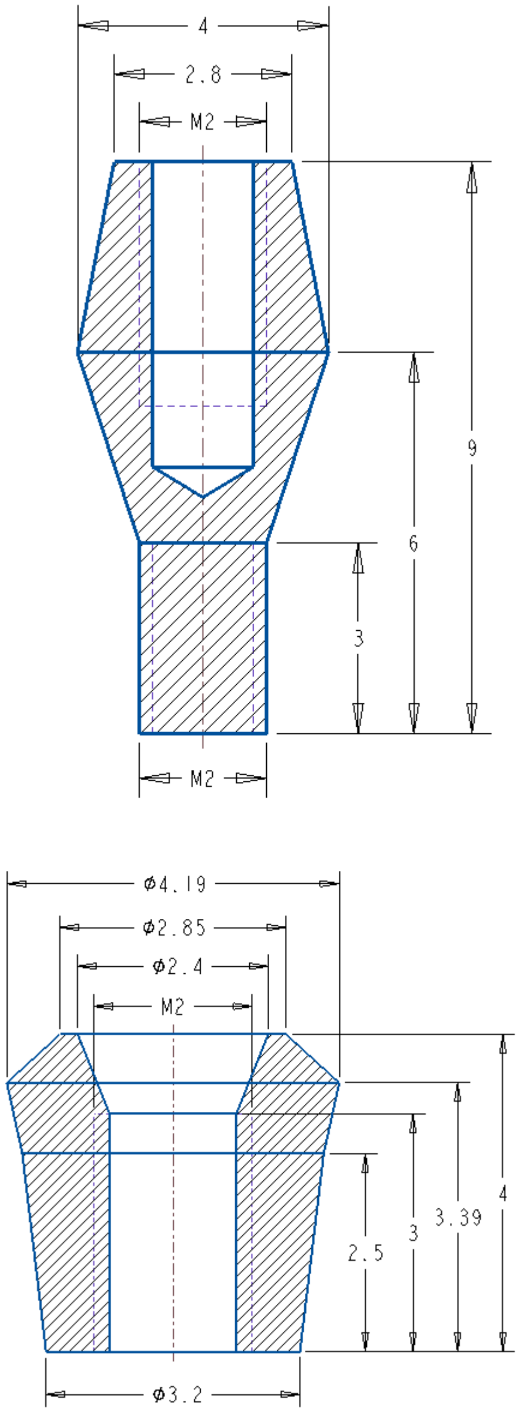

Figure 7: Abutment and sleeve

The consideration of anatomical aspects was the main reason why the geometry and manufacturing technology was changed. Our new implant variation was equipped with an external conical connection instead of an internal design, and it was manufactured with 3D printing. Laser sintering, also called 3D printing, is an additive manufacturing technology. Products are build-up of thin powder films layer-by-layer. An STL file must be generated before 3D printing, which is triangulated surface structure. A SISMA Mysint 3D printer was used with its own LMF technology. With Laser Metal Fusion, complex metallic parts and internal structures can be manufactured such as subperiosteal implants that are shown in Fig. 8. 3D printed parts are removed from the build platform and support material is separated. Afterwards, parts go through further post-processing steps.

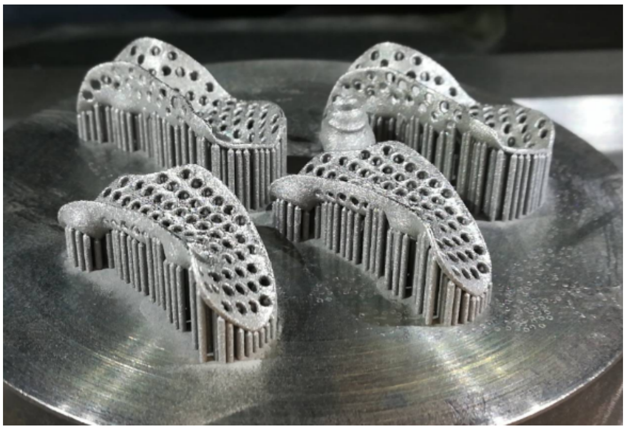

Figure 8: 3D printed subperiosteal implant with support material

The chosen redesigned geometry with external conical connection is visible in Fig. 9.

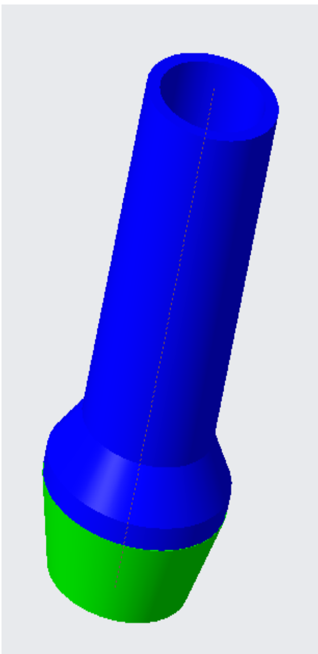

Figure 9: External conical connection geometry

The dimensions of the abutment and sleeve are shown in Fig. 10. These parts were machined from Grade 5 titanium alloy (Ti-6Al-4V).

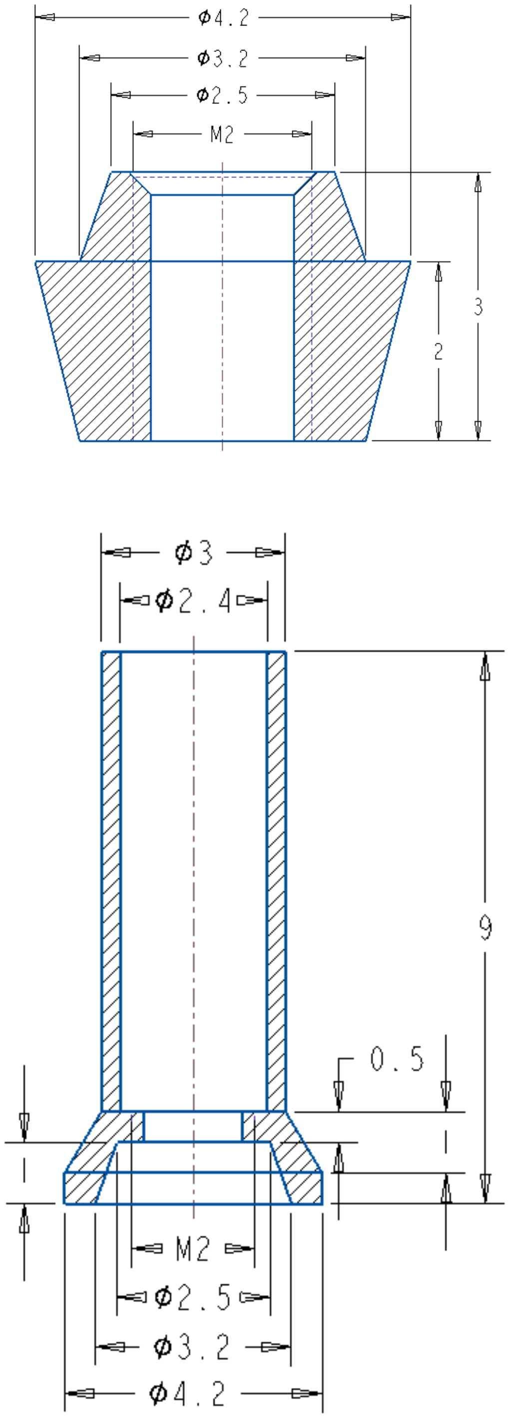

Figure 10: Sleeve and abutment

8 Finite element analysis of geometries with external and internal conical connection

Both variations were checked with finite element method after each design. First, our first solution is presented in Fig. 11 with internal connection.

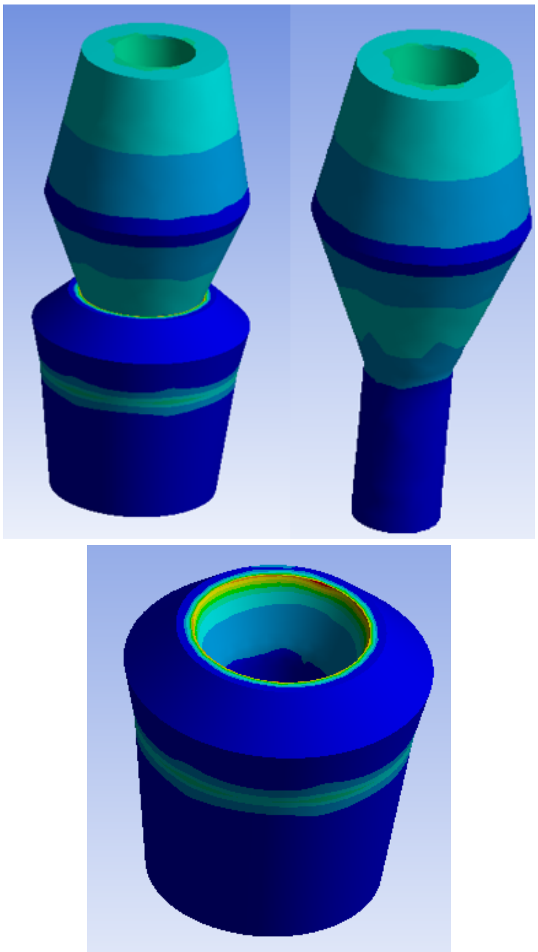

Figure 11: Finite element analysis of internal conical connection

This figure displays the conical surface at the internal connection with the highest stress levels; 275 MPa is the highest equivalent stress, which is distributed all around the upper edge of the cone. It can result in substantial displacement and the loosening of the screw. In the following (Fig. 12), results for the geometry with external conical connection are demonstrated.

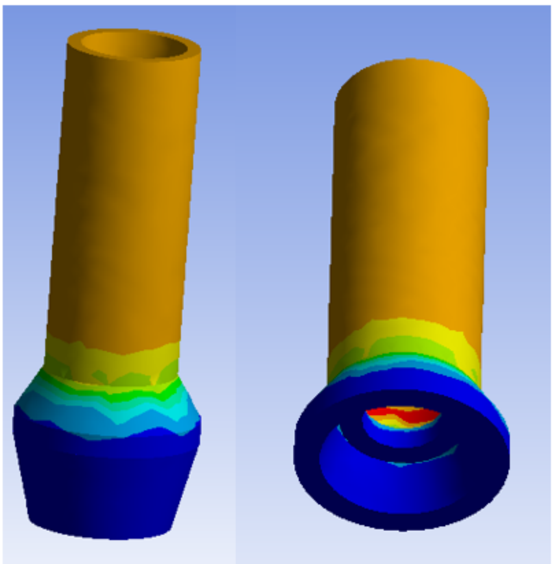

Figure 12: Finite element analysis of external conical connection

The highest stress levels in this case are at 240 MPa. However, in this case stress intensity will not cause screw loosening, so a higher mechanical stability can be achieved.

9 SUMMARY

We can experience a major development in modern-day implantology. Implant insertion is now considered as a routine procedure. The use of customised, patient-specific implants is also getting even more widespread. Thanks to individual implant design, different dentures are manufactured that fulfil the patient's needs and requirements. Manufacturing of these patient-specific implants is carried out with additive technological processes, which provide an opportunity for patients with insufficient bone volume for conventional cylindrical implant insertion. Different abutment designs, onto which dentures would be connected, were presented in this study. The abutment is connected directly to the sleeve that is fitted to the subperiosteal implant with micro-welding. In our study, the geometric design of the first variation of dual-phase implants together with the sleeve and abutment were presented. Later on, the recent, revised geometry was presented with the external conical connection of the sleeve and abutment. According to our latest research, this geometric design is appropriate. As may be expected, our studies are continued.

ACKNOLWLEDGESMENT

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