BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

FACULTY OF MECHANICAL ENGINEERING,

DEPARTMENT OF MACHINE AND PRODUCT DESIGN

FINITE ELEMENT MODELLING OF LOAD-BEARING MANDIBLE RECONSTRUCTION

The Booklet of the Thesis for the
Degree of Doctor of Philosophy

AUTHOR: **JÁNOS SIMONOVICS**
M.Sc. in Mechanical Engineering

SUPERVISOR: **DR. KÁROLY VÁRADI**
DSc

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1. Introduction

One of the most pressing problems of our generation is the successful treatment of the different cancer cases. In Hungary yearly approximately 33000 deaths can be contributed to malignant tumors, which are considered to be one of the most frequent causes. Among them the oral cavity tumors are responsible for 1700 death yearly.

The main reasons of the oral cavity cancer formations are the excessive alcohol consumption, smoking and in general inadequate oral hygiene. The oral cavity tumors are among the most easily diagnosable cancers; therefore during the regular dental appointments they can be easily screened. Early detection is a key factor considering the curability and recovery chances. In case of lately diagnosed cases the only solution is drastic surgery. If the bone is affected, the removal of the tumor is executed by resection method. Due to this procedure the continuity of the mandible is partly or completely ceased, its load carrying capability is reduced or completely vanished. After the resection the reconstruction of the mandible could provide a function, which is the same or at least close to the original one.

Nowadays this topic is more and more actively researched in biomechanical. Aside from cadaver examinations which are many times deemed circumstantial and difficult, the researches and developments with engineering devices are becoming overly popular, especially considering the finite element simulations which could play a valuable part.

1.1. The target of my research and the associated main questions

The main goal of my doctorial research is a thorough biomechanical examination of the loadable reconstruction of a mandible resection, which occurs in the current clinical practice in case of oral cavity tumors. I look for the answers to the following questions:

- What more punctual material properties, which can be found in the existing scientific literature, would apply to the human mandible? With the help of these properties could more sophisticated and realistic biomechanical models be built? Furthermore how these properties could be implemented in such a model?
- Could there be a difference from biomechanical modeling point of view by using the Cone Beam Computer Tomography, which is more beneficial for the patient, compared to the Multi-Slice Computer Tomography, which is considered as gold standard?
- What are the stress values in a mandible grafting, which is considered as a source during the osteotomy of the human radius? Which reinforcement techniques and osteotomy solutions could prove to be the most beneficial load cases concerning the bone?
- What are the stress values during the reconstruction with regular plates in case of the frequently occurring mandible resection within the critical sections considering the use of lock and non-lock techniques and mono- and bicortical screws?
- Which new implant constructions, aside from the already existing and used medical ones, could be comparable to the bone concerning the mechanical properties, which could also stimulate ossification and bone growth?

2. EXAMINATION METHODS

As an optimization to my previous biomechanical examinations with a simplified bone modeling method to provide better finite element bone models and more punctual material properties, I created bone sample cylinders from formalin fixed and macerated cadaver human mandible. These samples than I scanned using Computer Tomography (CT). After the creation of the correct geometry I applied press examination. I validated the modeling and simulation method based on the CT grayness values in light of the material properties by the support of the already carried out destructive examinations and CT measurements.

The models in my doctorate research are created upon output files from Computer Tomography. The radiation dose of the “conventional” Computer Tomography used in medical practice is several times higher than in the Cone Beam Computer Tomography (CBCT) used in the head region. I carried out comparison examinations on formalin fixed human head layers combined with known density elements between the layers by using both tomography methods to build up a finite element model with heterogeneous material properties considering the smaller radiation dose effect.

In the past to provide more information of the stability conditions by surgical techniques and the values of stresses and micro strains, laboratory measurements and examinations were carried out on cadaver bones. Due to the complicated circumstances of these measurements, nowadays the finite element analysis is considered more and more as a valid method in the biomechanical field. During my research I created models built with realistic geometries and CT based heterogeneous material properties. These models are in complete correspondence with the clinical practice; therefore I carried out finite element simulations on them. For the examinations I used the MSC Marc 2007 software. In case of both biomechanical models in the most critical regions I applied sub models.

Based on previous destructive examinations on human bone samples, a so called scaffold implant structure was designed using Ti-6Al-4V material. The prototypes were created by electron beam molding rapid prototyping method. On the samples I carried out electron microscope and measuring microscope examinations to determine the influences of the manufacturing process on the geometrical structure. I also used the samples to further determine the elastic modulus by applying destructive examination. Based on the results I checked the influence of the manufacturing direction on the mechanical parameters. The samples I further used to examine the magnitude of the porosity deviation due to the manufacturing.

3. NEW SCIENTIFIC RESULTS

3.1. Destructive examinations of cadaver samples

I composed a press examination plan on human bones to determine the elastic modulus of the mandible in order to refine the values extracted from the scientific literature. The bone samples from dead toothless human mandibles were prepared from partly formalin fixed (39 pieces) and partly macerated (57 pieces) pieces. There were several studies published concerning the tissue damaging effect of the formalin fixing method. The selections of the sampling regions were chosen based on the locations where the reconstruction plates are most likely screwed to the bone.

The samples taken from these regions I CT scanned first than I applied the press examination taking into consideration their orientation. In order to execute the MSCT scan of the human samples I used a special validation scheme, which contained etalon cylinders with known density and material properties. The result of the destructive material examination is shown on Fig. 1. I concluded that the measured results are below the average (found in the scientific literature), which in case of the formalin fixed method can be contributed to the tissue damaging effect.

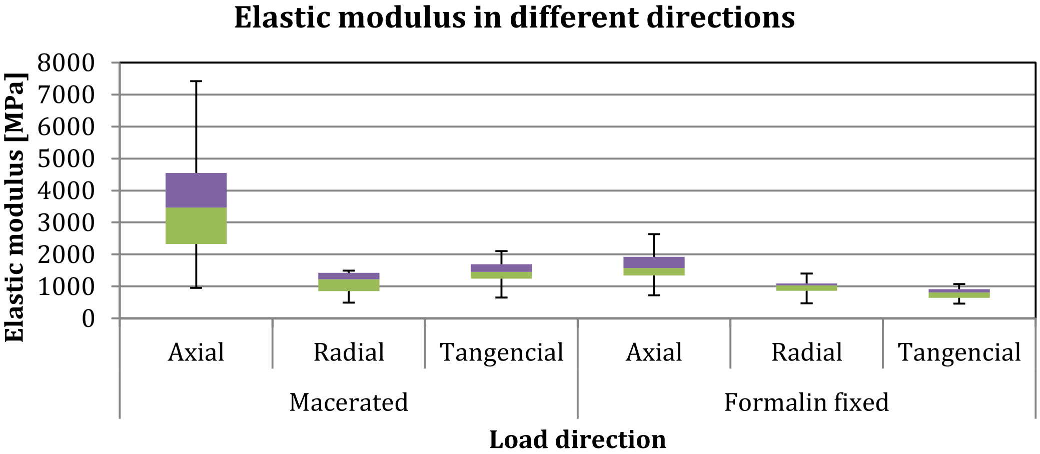

Fig. 1. Elastic modulus of cadaver samples, in different directions

I worked out an algorithm based on the CT data in order to validate the finite element models connected to the measurements. The validation based on the press examination on cadaver showed R^2=0.8433 correlation. The error rate of the elastic modulus of the examined samples are between 2.48%-6.91% compared to the real destructive examinations.

Thesis 1. *In order to optimize and validate the homogeneous simplified bone modeling method, applied during my biomechanical examinations, I developed a measuring process for pressing examinations on human bone samples. The process can be executed with sampling devices and it is connected together with computer simulation. With the help of the simulation the heterogeneous value of the elastic modulus of the lower jawbone cortical allocations (influenced by the bone density also), which in the current scientific literature moves on a wide range, can be determined. During the process I scanned the bone samples from cadaver using Computer Tomography with validating elements, than I applied the press examination. I validated my simulation models, which mechanical parameters are extracted from the grayness value of the Computer Tomography scan, based on the results of the destructive examinations.*

[1], [2], [3], [4], [5], [6], [7], [8], [9].

3.2. Comparison of the Cone Beam Computer Tomography (CBCT) and Multi-Slice Computer Tomography (MSCT) in case of formalin fixed cadaver head

For the examination, formalin fixed, 4 layered (each approximately 20 mm thick) toothless mandible of an old woman cadaver was used, which was provided by the Department of Human Morphology and Developmental Biology at SOTE. During the preparation of the head layers, in predetermined important points, known density elements (between 0.93-2.70 g/cm3 domains) were placed between the layers.

During the examination a calibrated 8-layer MSCT (General Electric, LightSpeed Ultra 8, GE Medical Systems, Waukesha, Wis) served as a reference, which was compared to CBCT (i-CAT, Imaging Science International, Hatfield, PA, USA).

The evaluation of the results regarding the phantom elements were based on the position-dependent and position-independent comparison. Furthermore I carried out the grayness value comparisons of the measured linear sections between each given phantom element.

In case of the position-independent evaluation, using statistical methods, I found that the values of the CBCT and the MSCT were all significantly differing from each other, except for the POM material. The P value of the heteroscedastic t-trial: PE: 0.0175; POM: 0.1906; Glass: 0.0125; AL: 0.0063. The comparison diagram of the grayness value is shown on Fig. 2.

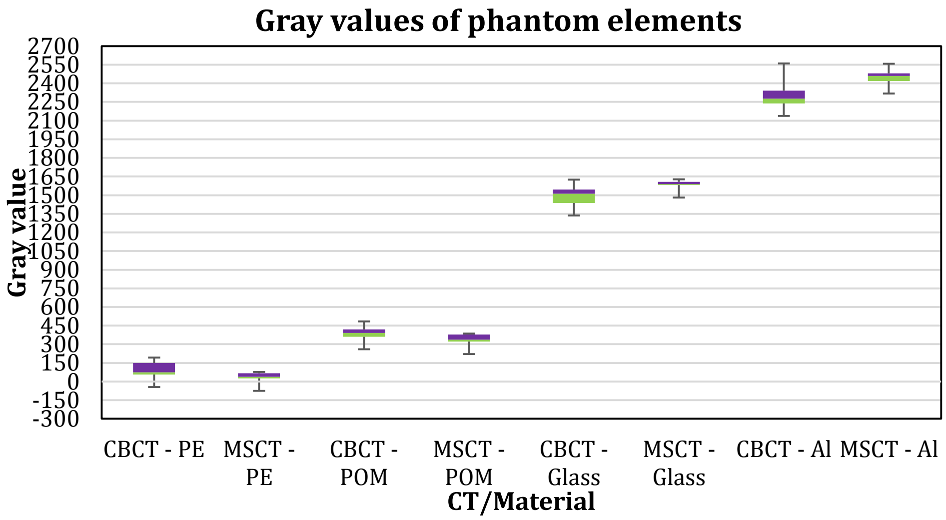

Fig. 2. Grayness values of the given phantom elements

In case of the position-dependent evaluation I compared the grayness values placed on the inner and outer arc of the mandible to their respective standard values in the frame of 9 correlation examinations (Table 1.). The linearly regressive equation:

$$CBCT_{gray\ value\ (calculated)} = A \cdot CBCT_{gray\ value\ (measured)} + B \quad (1)$$

where: $CBCT_{gray\ value\ (calculated)}$ – calculated value by Hounsfield unit definition,

A, B – coefficients,

$CBCT_{gray\ value\ (measured)}$ – gray value, measured by CBCT.

Table 1. Correlation of the CBCT measured values to the CBCT calculated values

	Examined area	Part	A	B	R^2
1	Skin surface	Left	1.1374	-116.36	0.9989
2		Middle	1.21	23.228	0.9956
3		Right	1.1708	-124.96	0.9986
4	Outer arc	Left	1.02	-106.37	0.9982
5		Middle	1.06	-37.83	0.9989
6		Right	1.08	-137.70	0.9990
7	Inner arc	Left	1.05	-46.90	0.9995
8		Middle	1.03	-110.79	0.9991
9		Right	1.08	-27.95	0.9991

I presented the grayness values in function of the distance in case of the examinations carried out on the measured linear sections of a cadaver between the given phantom elements. I applied 0.25mm steps during the sampling phase.

Based on the absolute differences I examined their frequency of occurrence in the given sections. I presented these with the relative cumulated frequency on a histogram. The summarized histogram of the absolute differences is shown on Fig. 3.

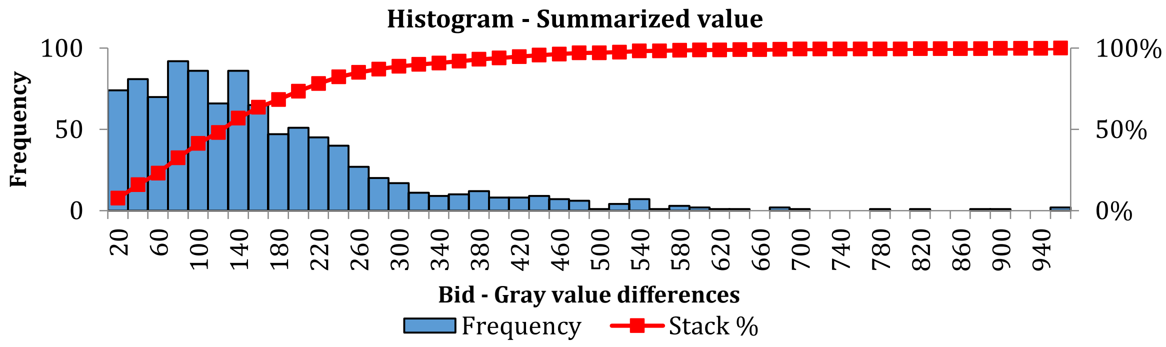

Fig. 3. Summarized histogram for absolute differences

I concluded that errors with 0-106 grayness values occur more frequently. Until 160 grayness value, examining subdivision values of 20, the occurrence of each given subdivision is between 7-10%. The load bearing sections of the implants can be contributed to the corticalis, therefore the errors in these sections are considered to be significant from the biomechanical modeling point of view. The grayness value of the corticalis is 3000, which can be found in the scientific literature. The examination results of the complete cross-section in this case means 5.33% error.

The linearly regressive correlation examination results are shown in the Table 2.

$$CBCT_{gray\ value\ (measured)} = A \cdot MSCT_{gray\ value\ (measured)} + B \quad (2)$$

where: $CBCT_{gray\ value\ (measured)}$ – measured gray value by CBCT,
A, B – coefficients,
$MSCT_{gray\ value\ (measured)}$ – measured gray value by MSCT.

Table 2. Correlation of the CBCT to the MSCT

Examined section	Markers at the end of the sections	A	B	R^2	n (number of sampling)
1	Glass	0.8977	55.572	0.9708	97
2	POM	0.6605	134.66	0.8948	91
3	PE	0.6111	26.323	0.8793	80
4	Al	0.8707	15.061	0.983	67
5	Glass	0.9437	66.786	0.9432	54
6	POM	1.1581	44.308	0.9596	52
7	PE	1.0365	31.041	0.8179	50
8	Al	1.1045	463.48	0.9085	51
9	Glass	0.7915	163.04	0.939	97
10	POM	0.8421	95.996	0.8696	107
11	PE	0.906	108.44	0.9425	114
12	Al	0.9183	154.89	0.9418	116

Thesis 2. *I developed a measuring process, which uses Computer Tomography scans of mandible (originated from cadaver) layers with known density validating elements between each layer. In this process the comparison of the Cone Beam Computer Tomography (CBCT - hundred times less radiation dose in the neck and head region) to the Multi-Slice Computer Tomography (MSCT – considered as golden standard) is based on the grayness values, which can also provide material properties during the finite element modeling.*

a. I concluded that in case of the position-independent evaluation by statistical techniques, the 4 examined known density elements are differing in case of the CBCT and the MSCT in all cases, except the POM material.

b. In order to examine the differences, by comparing the grayness values of a cadaver sample in the measured linear sections of each phantom element, I determined that the 0-160 grayness value errors are more frequently occurring in case of the examined 974 steps. Until the grayness value of 160, examining the subdivision values of 20, the occurrence of each given subdivision is between 7-10%. This means an error of 5.33% in case of the grayness value of the cortical allocation, which can be found in the scientific literature.

[9], [10], [11], [12], [13], [14], [15], [16].

3.3. Tibia examination

As a pre-study of the mandible resection, instead of the geometrically more complicated mandible bone, the first resections and also partial resection examinations I planned on the simpler, straight human radius bone. For the base of this examination I chose the case, which is considered as a graft source and it is in several points interconnected with the mandible. The lamb tibia is considered a valid model since 1992 as a substitute of the human radius in biomechanical examinations due to the experiment complications on the human radius. I examined, using finite element methods, the osteotomy bone fixation and fracture preventive reinforcement with different techniques (PIF – prophylactic internal fixation). During my research I created such a complex model, with which help more osteotomy scenarios can be examined using less computing capacity in case of the 4-point bending and torque testing selected by PIF techniques (Fig. 4.).

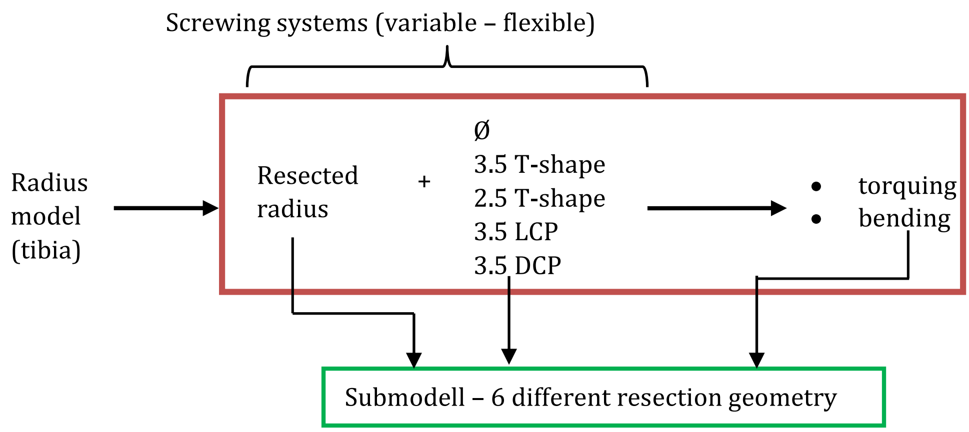

Fig. 4. System of the created models

Due to the acting loads usually the bone gets ruined instead of the implants. The defined resection area and closest to it the close vicinity of the plate screws could hold the potential locations for this damaging effect, therefore I examined these places.

In the models I developed density based material properties in order to execute finite element simulations. I used 4-point bending and torque testing for model examination. The acting stresses based on von Mises are shown on Fig. 5. I concluded that in case of the examined scenarios the 3.5mm LCP locking technique provides the best result considering the loads acting in the bone.

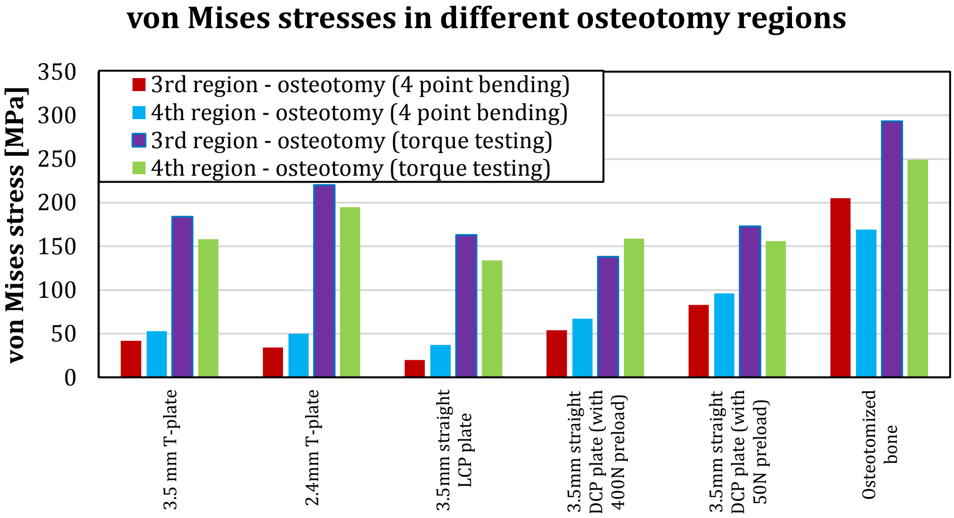

Fig. 5. von Mises stresses in the osteotomy regions

I examined 6 different osteotomy solutions using displacement field fitting method, on the sub model of the intact bone without reinforcement. I modeled the different versions of stress decreasing potentials that could occur in the medical practice (45° side-plated, 90° side-plated, 45° side-plated and overcut, 90° side-plated and over cut, 90° side-plated and rounded, 90° side-plated and drilled with „stop hole”). Fig. 6. shows two scenarios. It can be determined from the figures that in case of the rounded and drilled models the values are significantly lower.

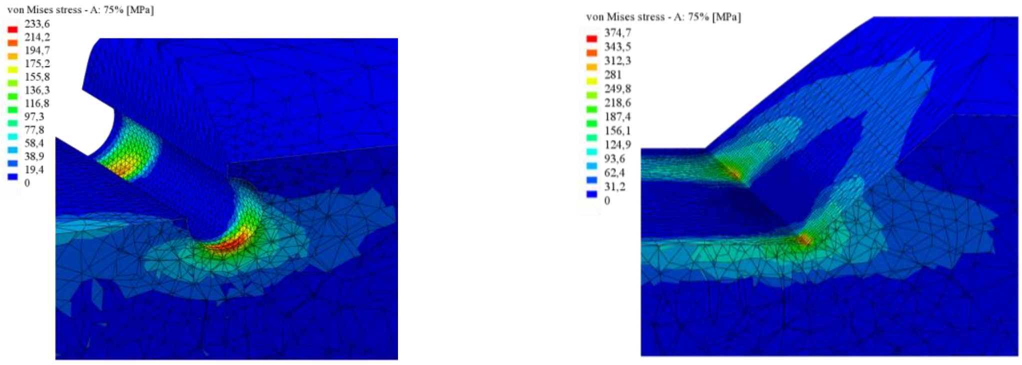

Fig. 6. von Mises stress during screwing in case of different osteotomy sub model solutions

The von Mises stress of the different solutions can be seen on Fig. 7.

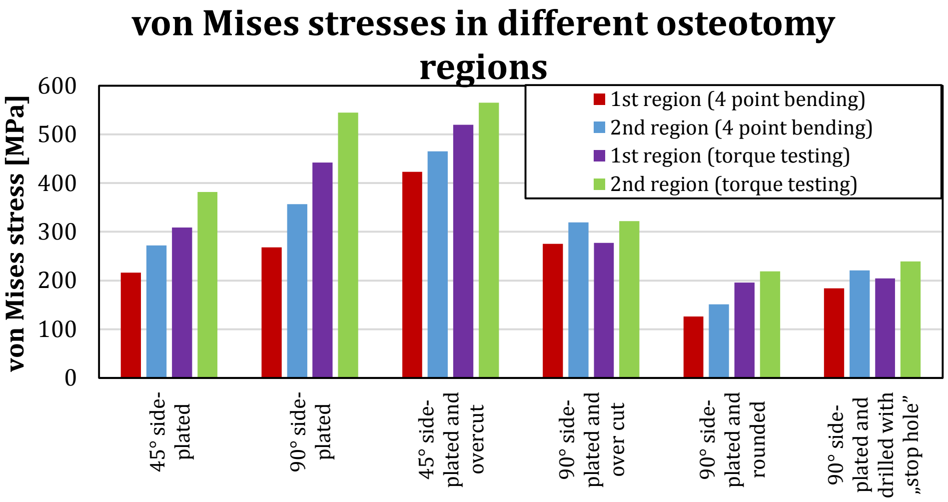

Fig. 7. von Mises stresses in case of the different submodel examinations

Thesis 3. *I developed integrated modeling and evaluation algorithms for the collateral PIF (Prophylactic Internal Fixation) fixation of straight bone during graft implantation of the mandible resection in order to create combined finite element models for plating and screwing techniques occurring frequently in the clinical practice. During the dissection of the graft partial resection sub model was created which size can be adjusted between given boundaries. The universal model can be paired, aside from several plating and screwing technique, with arbitrary resection geometries as well. This supports the creation of the most suitable cutting geometry for resection based on the mechanical load bearing capability. With the sub model inside the frame model, the simulations require less computing capacity and they are easier to examine and evaluate.*

a. I concluded within the frame of the given examination that the 45° side-plated resections used on the global model with 4-point bending and screwing loads in the 4 different examined systems, still the 3.5mm LCP locking technique provides for the PIF the smallest critical stresses (concerning fracture) arising in the bone and resection edges.

b. In my additional examinations, I proved with finite element simulations on the sub model that the rounded resection edge and the drilled resection edge provides the most favorable von Mises stress values within the 6 different resection geometries without reinforcement in case of a 40% volume removal. This finding could warrant a wider use of the accordingly created geometries in the clinical practice.

[9], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24].

3.4. Mandible examination

During the mandible examination I created models (4 basic cases) based on the more frequently occurring tumor resection cases affecting the complete cross-section. I consulted with oral cavity surgeons and discussed with surgeon consultants. I modeled regular reconstruction plates for the reconstruction and I examined its fixation with locking and non-locking (screw pretention), mono- and bicortical screwing (Fig. 8.).

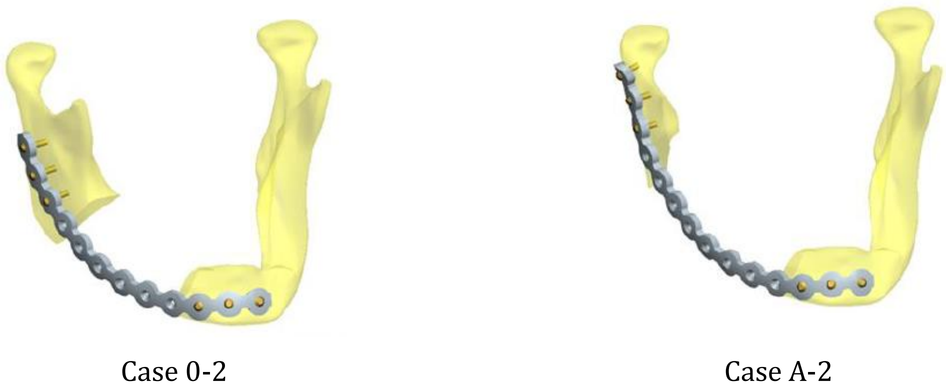

Fig. 8. Models with implants in case of 0-2 and A-2 situations, where the 0-2 and A-2 mark the domain boundary of the different resections

On the created models in the screwing areas additional sub models were defined. I carried out finite element simulations on these models with anatomically correct load cases and boundary conditions (Fig. 9.).

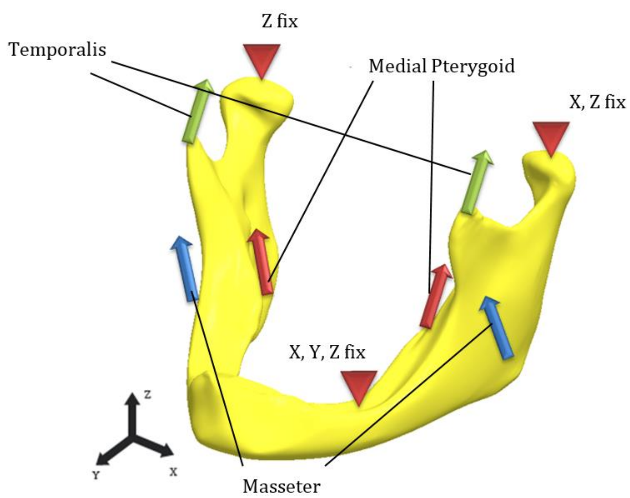

Fig. 9. Loads and boundary conditions on the mandible

The material parameters for these simulations were provided by the data extracted from the CT scans. During the global examinations I considered 16 scenarios and I evaluated the von Mises stresses and strain deformations (IFS Inter-fragmentary Strain used in medical field).

I concluded that based on the von Mises results of the examined scenarios the mono locking system should be mainly proposed. Taking into account the IFS theory, the locking and non-locking systems are appropriate in case of the screw loosening; however the locking system could provide a more stable solution on the long run due to its lower values.

Among the examined scenarios the 4th screwing location of the A-2 case is the most critical region, therefore with the selection of this screwing area I carried out further sub model simulations (displacement field fitting method) to which I used real screw geometries.

Due to the high von Mises stress arising in the bone, quite certainly the damage of the bone can be expected in this case.

Thesis 4. *I developed a designing-evaluating algorithm for such complex models with heterogeneous material properties of the most important jawbone resections which are widely used in the clinical practice. The algorithm can be used to examine the screw implants for arbitrary fixations with the help of sub model created in the area of the screws used with reconstruction plates (used as golden standard). Among the adjustable parameters there is the complete screw geometry in case of all mono-, bicortical, locking and non-locking systems.*

I determined by examining the 4 resection domains ,which are most frequently used in practice, with mono-,bicortical, locking and non-locking systems. Based on the arising stress in the bone within the screwing environment the mono locking system provides the most favorable load transmission condition. In case of lower bone density to provide better reconstruction possibility the locking bicortical system should be applied. My examination results are confirmed by the use of real screw geometry and sub model.

[9], [15], [16], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39].

3.5. Development and examination of a new load bearing implant structure

I carried out the development and examination of a unique, controlled porosity RPT implant structure based on my personal measurement results from cadaver samples combined with previous examination extracted from scientific literature. The main goal and target with the created structure is to achieve an elastic modulus which is closer to the elastic modulus of the bone and its structure configuration can stimulate ossification and bone growth, this way speeding up the recovery process and time.

During my examination I created models based on 6 different structures (2 different geometry, 3-3 different porosity degree). The production of these models into samples was done by electron beam molding rapid prototyping manufacturing method from Ti-6Al-4V biocompatible material.

Following the manufacturing of the samples I used Scanning Electron Microscope (SEM) to understand the structural texture of these parts. After consulting the results I concluded that the samples do not contain geometrical failures that could cause material tear through several columns or influence the destructive examination in the negative direction (Fig. 10.). I double checked as well the material composition (EDAX) of the samples.

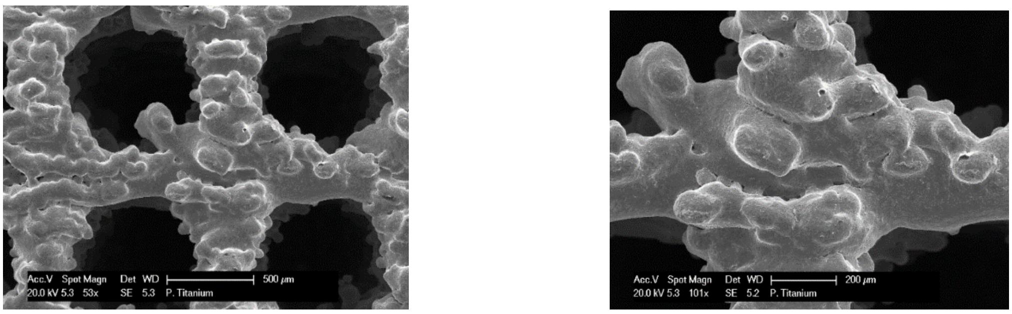

Fig. 10. Scanning Electron Microscope images of the scenario number 6 in 50x and 100x magnification

I further carried out porosity tests in order to determine if there is any influence on the structure that could be contributed to the manufacturing process. Aside from the determination of the porosity values I also checked with Stereo Microscope the real pore and column sizes. Then I compared these with values defined in the CAD model. I concluded that the planned porosity values in every case decreased in the produced samples. The pore sizes were in every case below the planned values; however the column sizes bared the opposite tendency.

I carried out the destructive press examination on the samples. My goal was to determine the elastic modulus by registering force and displacement diagrams. I especially focused on the effects of the manufacturing direction on the mechanical parameters. During the examination I used 120 samples. I concluded that in case of the EBM technology the manufacturing direction has an influence on the mechanical properties. Compared to my previous cadaver examinations I managed adequate elastic modulus with the prepared structures (Fig. 11.).

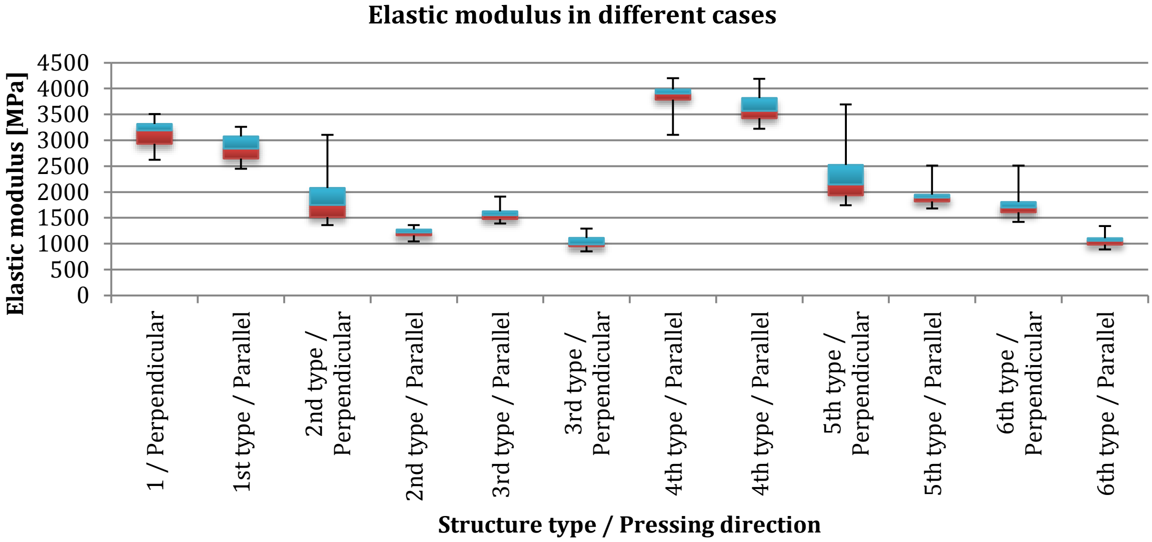

Fig. 11. Elastic modulus in the different cases

I identified connections in order to estimate the elastic modulus of the prepared structures in the used porosity domains (Fig. 12.).

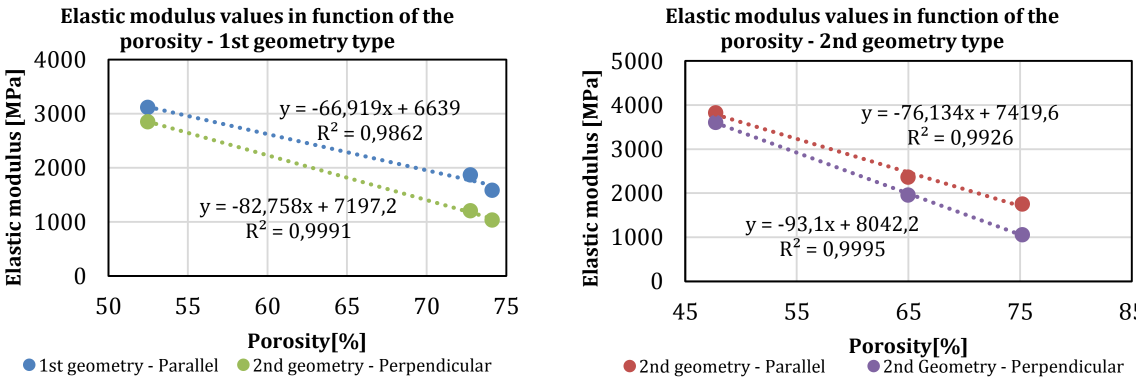

Fig. 12. Elastic modulus values in function of the porosity

Thesis 5. *I developed a porous implant structure which can be produced by using the electron beam molding rapid prototyping method (EBM). Its mechanical property values are closer to my results extracted from the cadaver bone examinations than compared to the regularly used plate implants. The designed pore structure in the implant stimulates ossification and bone growth.*

a. I proved that in case of the designed structures, produced from Ti-6Al-4V material with general machine parameters using electron beam molding, the porosity values are always below the planned numbers. Its magnitude is between 4.31 – 25.89% in case of the *examined structures. I developed a solution with the designed structures which provide the most optimal conditions for ossification and bone growth.*

b. I demonstrated that the elastic modulus between the structures produced with EBM technology can differ as much as 40% concerning the direction parallel and perpendicular to the manufacturing direction. The elastic modulus values of the designed structures correspond to the results from my cadaver examinations.

c. Between the elastic modulus values and the porosity values I created a linear regression. Based on this it can be stated that in case of the first geometrical design in the 52.48 – 74.12% porosity domain, the following equations can comprise the change of the elastic modulus:

- *perpendicular to the manufacturing direction:* $y = -66.919x + 6639$ ($R^2=0.9862$);
- *parallel with the manufacturing direction:* $y = -82.758x + 7197.2$ ($R^2=0.9991$),

in case of the second geometrical design in 47.73 – 75.21% porosity domain:

- *perpendicular to the manufacturing direction:* $y=-76.134x+7419.6$ ($R^2 = 0.9926$);
- *Parallel with the manufacturing direction:* $y = -93.1x + 8042.2$ ($R^2 = 0.9995$).

[9], [40], [41], [42], [43], [44]

4. THE PRACTICAL USE OF THE RESULTS

Through my cadaver examinations it can be stated that the values are below compared to the mechanical parameter values of the bone which can be found in the scientific literature. In case of the older generation the possibility of a mechanically weaker bone must be considered, which is mainly true to population affected by my examinations of the mandible tumors. The finite element simulation validations based on the press examination results showed that the material properties used in regular practice could contribute a significant error rate in the biomechanical model; however the required parameters could be patient specifically built by applying the data from CT scans.

During my comparison of the CBCT and MSCT methods I concluded that the CBCT, which uses hundred times less radiation load, results can be used for biomechanical modeling with minimal error rate. It can be stated that the possible errors can be corrected by scans with phantom elements.

My simulations provide comparison bases for possible bone reinforcement scenarios in case the human radius graft section is removed and the bone becomes significantly weaker. The examined geometrical solutions of resections efficiently support the avoidance of a second fracture usually occurring after the osteotomy.

I identified the weak points of the reconstruction options modeled on the complete mandible resection through my examinations. I proposed the selection of the most optimal technique based on my simulations in the cases more frequently occurring in the clinical practice. The designed model provides the possibility to examine the bone loads in arbitrary screw geometries in the different screw locations. By using the results the frequently occurring implant fracture and extraction in clinical practice can be easier avoided and new geometrical implants can be further developed.

The designed structures, which can be produced by rapid prototyping, could provide samples, which mechanical properties are closer to the properties of the bone; therefore the chance of extraction due to the stiffness of the implants is reduced. The porous structure stimulates bone growth which results a faster ossification and recovery of the patients.

5. PERSONAL PUBLICATIONS CONNECTED TO THE THESIS POINTS

[1] T. Bodzay, G. Sztrinkai, T. Gál, J. Simonovics, és K. Váradi, „How bilateral iliolumbar fusion increases the stability of horizontal osteosynthesis in unstable pelvic ring injuries?”, *Arch. Orthop. Trauma Surg.*, ápr. 2013.

[2] J. Simonovics, K. Váradi, és P. Bujtar, „Biomechanikai csontmodell építésének lehetőségei”, *GÉP*, köt. LXII II, o. 24–27, nov. 2011.

[3] J. Simonovics, K. Váradi, és T. Bodzay, „Study and examination of the implements used for securing pelvis bone”, *Biomech. Hung.*, köt. III, sz. 1, o. 215–223, 2010.

[4] J. Simonovics, K. Váradi, és T. Bodzay, „Medencetörés rögzítési technikák vizsgálata”, *GÉP*, sz. 10–11, 2010.

[5] J. Simonovics, K. Váradi, P. Bujtár, A. Szűcs, és Z. Fejér, „Macerált mandibula minták roncsolásos biomechanikai vizsgálata”, *GÉP*, sz. 2013/7. LXIV., o. 32–35.

[6] J. Simonovics, P. Bujtár, K. Váradi, A. Szűcs, és Z. Fejér, „Compression test of the mandibular cortical bone: A cadaver study assessing formalin treated or macerated bone specimens.”, *Biomech. Hung.*, köt. Évf. 7., 2014.

[7] J. Simonovics, K. Váradi, és T. Bodzay, „Massa lateralis medencetörés implantátumainak vizsgálata”, *OGÉT 2010 XVIII Nk. Gép. Találk. Nagybánya 2010 Ápr. 22-25*, o. 372–375.

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6. APPENDIX

Exposition:

CAD	Computer Aided Design
Cadaver	Dead body
CBCT	Cone Beam Computer Tomograph
DCP	Dynamic Compression Plate
EBM (SEBM)	Electron Beam Melting (Selective Electron Beam Melting)
EDAX analysis	Energy Dispersive Analysis of X-Rays
Formalin fixed	Fixation in Formaldehid
IFS	Inter-fragmentary Strain
LCP	Locking Compression Plate
Macerated	Soaked bone in warm water (then treated in steam and whitened)
Mandibula	Lower jaw
MSCT	Multi-Slice Computer Tomograph
PIF	Prophylactic Internal Fixation
RPT	Rapid Prototyping