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APPLICATION OF COMPUTER MODELS OF MITKOVIĆ SELFDYNABIZABLE INTERNAL FIXATOR IN REHABILITATION OF FEMUR TRAUMAS

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Miroslav Trajanović[1], Nikola Korunović[1], Jelena Milovanović[1], Nikola Vitković[1], Milorad Mitković[2]

[1]Faculty of Mechanical Engineering Niš, University of Niš
[2]Faculty of Medicine and University Orthopaedic and Traumatology Clinic,
University of Niš, Serbia
E-mail: korunovic.nikola@gmail.com

Abstract. *This paper deals with the use of computer aided technologies in orthopedics, especially concerning the application of Mitković selfdynamisable internal fixator to rehabilitation of human femur traumas. Unique place of Mitković fixator among other solutions is briefly explained, followed by description of steps through which CAD models of femur and implants are created. Those steps involve the use of medical imaging and polygonal model healing as well as surface and solid modeling. The rest of the paper is focused on two different applications of mentioned CAD models. On one hand, they are used in the application for planning of orthopedic operations, which has been developed by the authors. On the other, they serve as the basis for creation of finite element models, which may be used for optimization of implant design and its location on the bones.*

Key words: *implant, internal fixator, femur, finite element analysis (FEA), computed tomography (CT), operation planning, biomedical engineering*

1. INTRODUCTION

Computer aided technologies are being increasingly used for the solution of many problems associated with Biomedical Engineering. A significant number of these have proven to be especially useful in orthopedics. Medical imaging is often used for obtaining patient-specific data, which usually serves as the basis for CAD modeling of bone-joint system and surrounding tissue. The resulting CAD models find many practical applications. For example, rapid prototyping (RP) is used for fabrication of custom-made implants and finite element analysis is used for optimization of implant design and location. CAD models may also be used for preoperative planning by virtual implant positioning.

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This paper focuses on most of the mentioned techniques applied to Mitković selfdynamisable internal fixator, in scope of a larger project that deals with application of computer-aided technologies in surgery of bone-joint system.

Internal fixation of bone involves a temporary or a permanent implant insertion into the human body. Commonly used materials for internal fracture fixation are titanium alloys, stainless steel or cobalt chromium molybdenum alloys that are defined as osteosynthetic materials [1].

The most common types of internal fracture fixation are neutralization plate and intramedullary nail. Their main negative feature is that they keep the parts of fractured bone separated. In this way healing of the fracture becomes possible only after they undergo some structural failure. In [2] it may also be seen that stress concentration and absolute values of stress tend to be high in those implants, which in a large number of cases leads to early implant fatigue failure.

Internal fixation using the Mitković selfdynamisable internal fixator in the treatment of trochanteric femoral fractures, provides dynamization and compression of the fracture site in two axes (axis of the femoral neck and femoral diaphyseal axis)[3]. The dynamisation and compression of the fracture provide effective healing of the fracture, early activation and mobilization of the patients, accompanied by the minimal possibility of mechanical complications development (disintegration, falling out of pins, head perforation, banding or bursting of the implants). The dynamic internal fixation is easy to perform; the method itself is minimally invasive while the periostal vascularization remains intact [4], [5].

2. CAD MODELS

The first phase in creation of CAD model of the femur started with 20 scans of femur samples (both left and right) that were scanned by Toshiba's Aquilion 64-slice computer tomography system at isotropic resolution of 0.5 mm. These images were exported from CT in DICOM format and further processed and edited in medical image processing 3D software package that was used to obtain the primary 3D models utilizing density segmentation techniques. At the end of the process image files were exported to STL format and imported into appropriate CAD software for reverse modeling (Dassault CATIA V5).

In the second phase, the model has been cleaned and healed, so that irregularities, caused by difficulties in recognizing the boundaries between cancellous and cortical bone structure or by osteoporosis were corrected (Fig. 1).

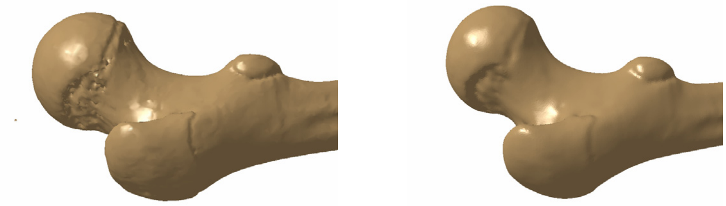

Fig. 1. Part of the polygonal model of the femur, before and after the application of healing and smoothing techniques

Besides the CAD model of the femur, CAD models of implants have been created, which include trochanteric and condilar bars (Fig. 2), brackets and screws.

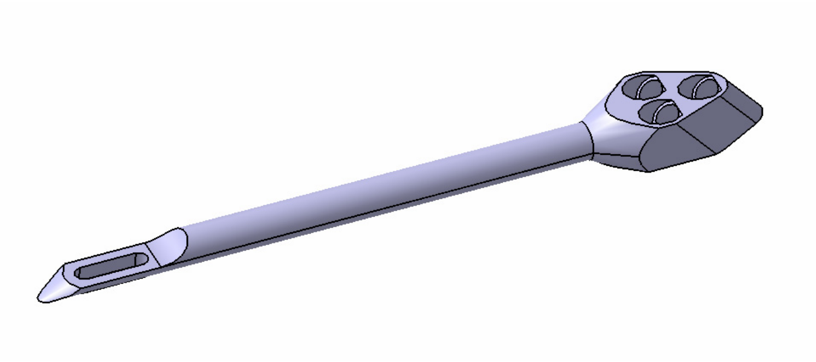

Fig. 2 Basic part of selfdynamizing implant with trochanteric unit – trochanteric bar

Using the described CAD models, parametric assembly of femur and implant has been created, in which implant may be positioned according to surgeon's intention, while some constraints, like location of screws inside femur head or femur shaft, always stay satisfied (Fig. 3). The assembly enables a number of different length bars to be used alternatively.

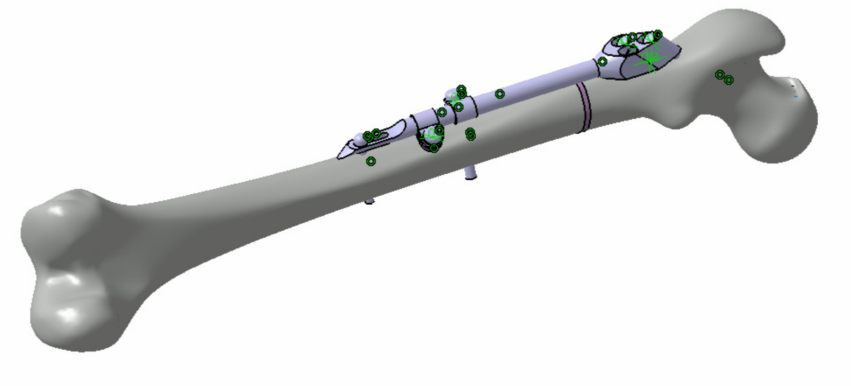

Fig. 3 Femur-implant assembly

3. APPLICATION IN SURGERY PLANNING

Femur and implant models, described above, have been used in an application for planning of orthopedic operations, which is being developed by the authors as a part of ongoing research. The first final version of the application was created in accordance with specified requests, which were defined in cooperation with surgeons and orthopedists [8]. The application enables surgeons and orthopedists to plan the operations by: defining adequate fracture according to standard classification, choosing proper implants, measuring dimensions on bone and implant models, etc.

The application consists of two software modules:

- Module for operating in 2D space, which enables manipulation with x-ray images (Fig. 4),
- Module for operating in 3D space, which enables manipulation with 3D bone and implant models in the similar way as in CAD software (Fig. 5).

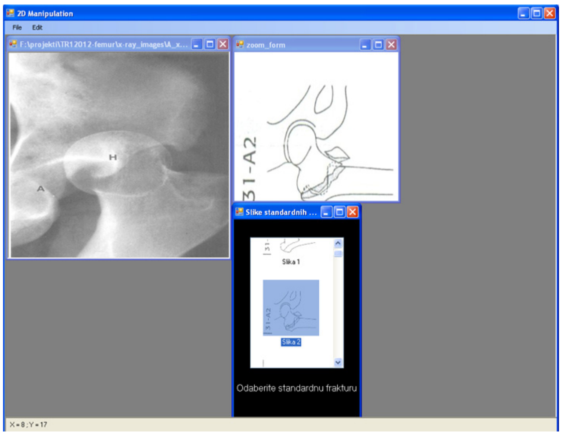

Fig. 4 2D program module

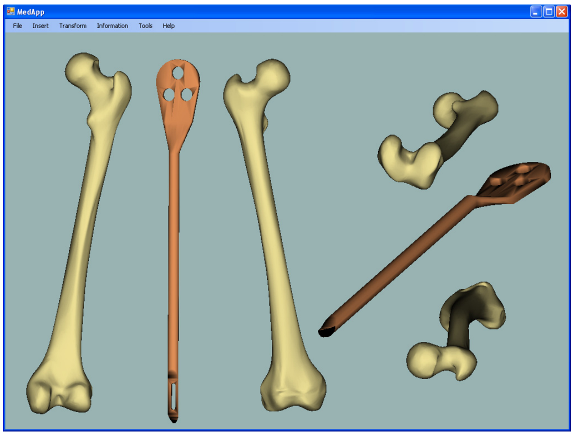

Fig. 5 3D program module

3.1. 2D application module

2D application module consists of a number of system and user defined classes. The basic system classes belong to Graphical Device Interface+ (GDI+) API (API which enables work with 2d graphics), which succeeds basic GDI, used for previous versions of C language (C/C++). GDI+ is used by all current versions of C language, including C#.

2D module enables x-ray image manipulation in 2D space. Current version of the 2D module application includes the following functions:

- Loading of x-ray images in raster format: bmp, gif, png
- Loading of x-ray images in vector format: wmf, emf
- The basic transformations in 2D space, such as: scaling, zooming in/out, rotation, translation
- Measuring adequate dimensions from images, which is shown on status bar.
- Defining fracture type by specified classification.

3.2. 3D application module

3D application module is constructed of a number of system and user defined classes. System classes originate belong to DirectX API (Application Programming Interface). DirectX API enables full use of computer's graphic resources, and contains a number of methods and classes which facilitate working with specific 3D modules (in this particular case with polygonal model-mesh). The difficulty while creating applications that use this API is the limitation of creating applications which function in Windows only. DirectX applications may function in Linux; however, additional applications (such as Wine), which on occasion don't provide either desired results, or complete functionality, must be utilized. User defined classes are defined at the level of either Windows forms or utility classes.

The main functions of 3D module are:

- Loading of 3D bone and implant models.
- Basic geometrical and visual manipulation with models in 3D space, such as: scaling, three axes translation and rotation, zooming in/out.
- Rotation of full view (bone and implant assembly).
- Positioning of the implant model on the bone model.

3.3. The application of implant CAD model

In 2D application module, the raster image of a suitable implant is directly compared with the loaded x-ray image of femur. It is possible to perform basic transformations with raster images of femurs and implants.

3D CAD implant model is used in 3D application module. This module can operate with polygonal models formed as DirectX structure.

The process of creating DirectX models is performed in two steps:

- The first step is the creation of implant and bone CAD model. This step has been thoroughly explained in the previous part of this paper [8].
- The second step is a transformation process of implant and bone polygonal model in the DirectX data model. This step contains two important phases:
  a) Transformation of a polygonal model from CAD software into an adequate format to be further processed. After a detailed analysis of various polygonal model formats and their application in real 3D software packages, the STL format has been selected. STL format is suitable, for it contains data of points coordinates which compose triangles of a polygonal model, as well as vectors of triangle normals (which are significant for calculations of both triangle visibility in 3D space, and dispersion of light on the model).

b) Transformation from STL format to DirectX format-.X. For this transformation Blender software (open source software) is used, which is intended for computer graphics purposes (computer gaming, CAD, etc.) This application enables additional editing of imported polygonal model, if so required (removing, adding, moving points, adding material to the model, etc.). After editing, polygonal model is exported to the .X format, designed for the application for planning of orthopedics operations. (Fig. 6).

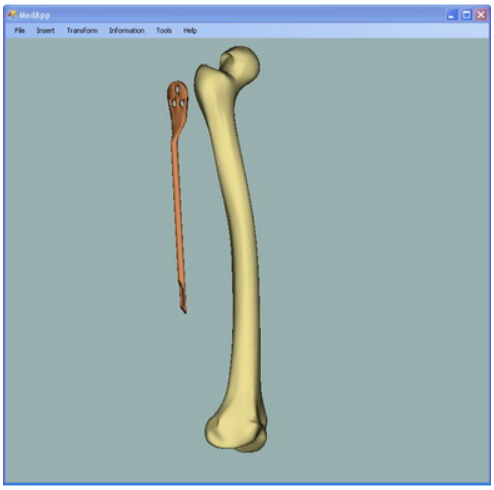

Fig. 6 3D models of implant and femur (.X) in the process of dimensional and positional adjustment, shown in the application window

The designing process is highly complex; however, it can be accelerated in the following way. Instead of individually processing each model, an algorithm which enables operating with parametric model (designed in CATIA software) will be created in the subsequent version of the application. The parametric model will proportionally adjust its dimensions to the measurements of corresponding radiology image (x-ray or CT scan), which are defined as parameters of Parametric model.

4. APPLICATION IN FEA

CAD model of the femur has also been used as a basis for finite element (FE) model building, which is intended for structural analysis of femur itself and femur-implant assembly. The model has been built trough following phases:

1) Segmentation of inner structure - zoning
2) Assignment of material properties
3) Creation of finite element mesh

The following two approaches to modeling bone material for use in FEA are most often used: assignment of material properties to each finite element separately, based on correlations with bone density that is determined from CT scan [9] and assignment of equivalent material properties to finite elements grouped inside various bone segments. Using the first method, FE model of the bone may be created in a very short time but errors are introduced in representing it's interior, especially if dimensions of finite elements are significantly greater than the thickness of bone segments. Thus, in current research the second approach has been used.

In the first zoning step, two clearly distinguishing zones, compact bone and intermedullary cavity, have been constructed. The remaining volume that corresponds to spongious bone has then been divided into a number of zones, according to common distribution of trabecular density, which is the consequence of bone remodeling. The idea, taken from [10] has been expanded from 2D to 3D model, which dictated the use of advanced 3D features of CATIA CAD software. The zone of fracture has also been created and then used in FEA of femur-implant assembly.

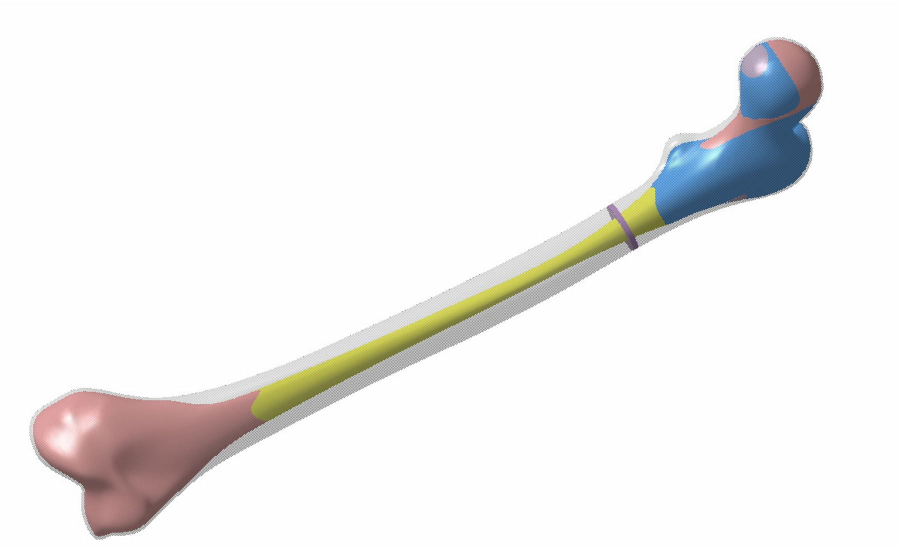

Fig. 7 Zones created in the interior of femur model, including the zone of fracture. The zones inside spongious bone have been created in such way that they correspond to volumes of different trabecular density. Equivalent moduli of elasticity, according to Table 1, have then been assigned to each of the zones

On the envelope of femur model the surfaces have been created, which correspond to areas at which joints, muscles and ligaments act. Then the finite element mesh has been created inside of the zones (Fig. 8).

Table 1 Equivalent moduli of elasticity used in FE model [10]

Zone - material	Modulus of elasticity [MPa]
Compact bone	17000
Spongious bone of higher trabecular density	400
Spongious bone of lower trabecular density	100

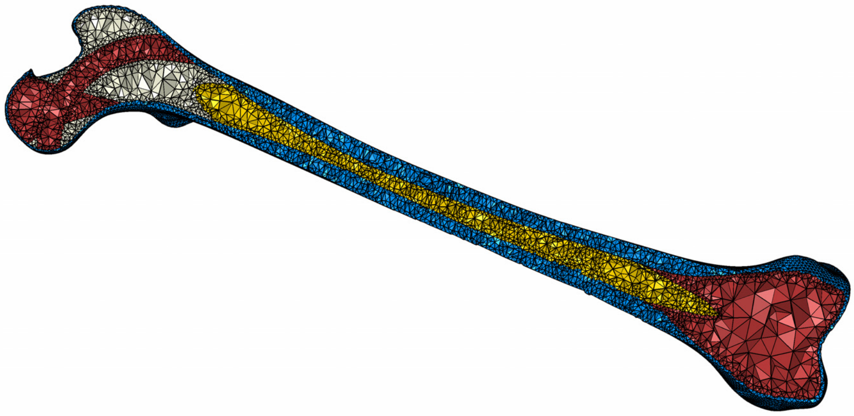

Fig. 8 Finite elements created inside various zones of finite element model

Using finite element model of femur, preliminary analysis has been conducted, where loads have been defined in a way that corresponds to one-legged stance, as in [7] (Fig. 9).

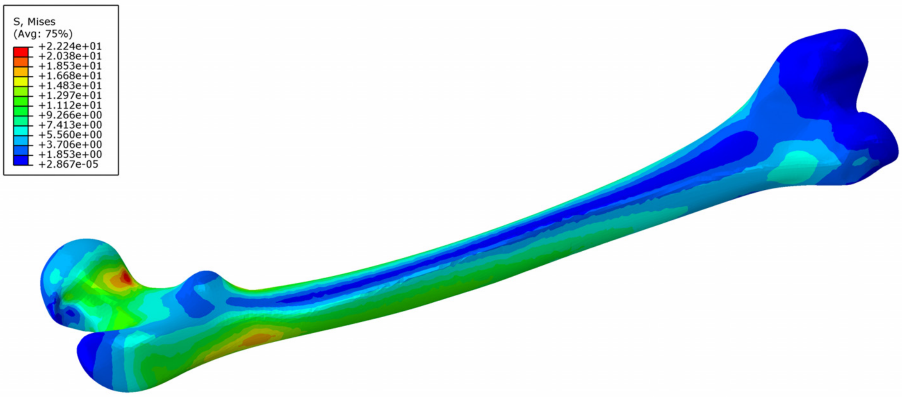

Fig. 9 Equivalent stress field on femur surface, obtained as a result of one-legged stance simulation

After the FE model of femur has been checked trough preliminary FEA, FE model of femur-implant assembly has been constructed. Femur model has been combined with subassembly that consisted of trochanteric bar and a number of brackets and screws [2]. Fracture zone on femur shaft has also been taken into account, which allows for simulating the state of the fracture in different healing stages by changing of its elasticity modulus (Fig. 10).

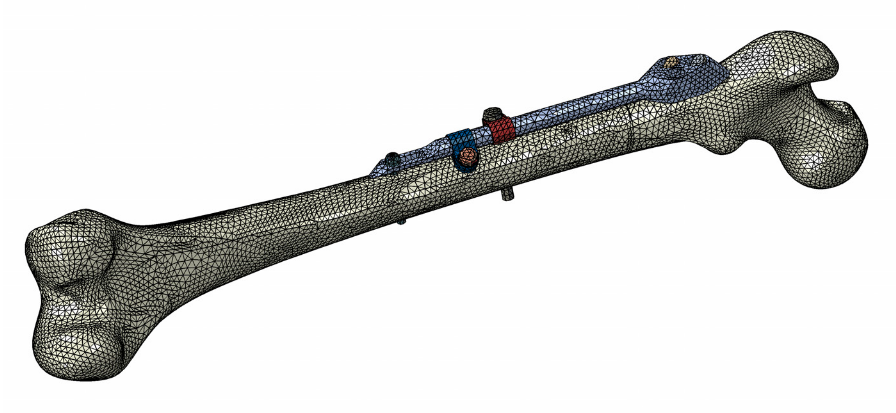

Fig. 10 FE model of femur-implant assembly

Using the FE model of femur-implant assembly a preliminary FEA has also been performed, under the same load conditions as in FEA of intact femur (Fig. 11). The analysis has confirmed model integrity and, as expected, has shown that the stress on the implant, and especially on screws, is higher than the stress on the bone itself.

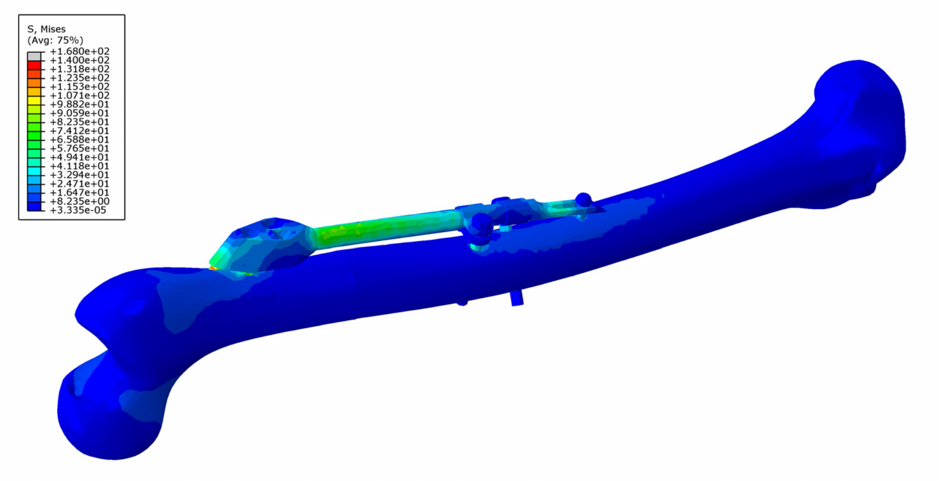

Fig. 11 Equivalent stress obtained by preliminary FEA of femur-implant assembly

By creation and preliminary analysis of FE models described in this chapter, the methodology has been established, which may be used for stress analysis of specific patient's femur combined with accordingly sized implant, where position and dimensions of fracture zone may be varied. This enables for various studies to be conducted, some of them being:

- The influence of fracture heeling degree to implant durability
- The influence of implantation technique to durability of implant
- The influence of implant dimensions to bone and implant durability

Selected studies are planned to be conducted in the following time period and it is expected that they help surgeons in choosing the most adequate implant size and implantation technique for certain type and location of femur fracture. The application of methods described in this chapter should also facilitate the creation of new, optimized and more durable implant designs.

5. CONCLUDING REMARKS

This paper has focused on application of computer aided modeling in preoperative planning and implant stress analysis. A methodology for design and analysis of the implants and patient-specific bones is shown and its advantages described.

Both surgeons and patients may benefit from current research results. Described techniques lower the risk of unsuccessful operative outcomes, by reducing the possibility of inadequate implant selection and placement. They also facilitate production of custom-made implants, which fit in trauma areas in the best possible way.

There are numerous possibilities for application of presented models and methodologies in orthopedics. In the frame of the current research a number of studies is going to be conducted that could further improve current implant design and techniques for operative positioning. Those studies should also help in improving of the application for orthopedics operations planning made by the authors, which is, in its next version, going to be enhanced with the new functionality.

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PRIMENA RAČUNARSKIH MODELA SAMODINAMIZIRAJUĆEG UNUTRAŠNJEG FIKSATORA PO MITKOVIĆU U SANIRANJU TRAUMA FEMURA

Miroslav Trajanović, Nikola Korunović, Jelena Milovanović, Nikola Vitković, Milorad Mitković

Ovaj rad bavi se primenom računarski podržanih tehnologija u ortopediji, na primeru upotrebe samo-dinamizirajućeg unutrašnjeg fiksatora Mitković u lečenju trauma humane butne kosti - femura. Najpre je ukratko objašnjeno jedinstveno mesto koje fiksator Mitković zauzima među ostalim sličnim rešenjima, nakon čega je dat opis koraka kroz koje su kreirani CAD modeli femura i implantata. Ovi koraci obuhvataju upotrebu slikovno-dijagnostičkih metoda, metoda "čišćenja" i "ozdravljivanja" poligonalnih modela kao i površinskog i zapreminskog modeliranja. Ostatak rada skoncentrisan je na dve različite primene pomenutih CAD modela. S jedne strane, oni se koriste u okviru računarske aplikacije za planiranje ortopedskih operacija koja je kreirana od strane autora. Sa druge, koriste se i *kao osnova za kreiranje modela namenjenih analizi primenom metoda konačnih elemenata, čijom se upotrebom može vršiti optimizacija veličine fiksatora i njegovog položaja u odnosu na tretiranu kost..*

Ključne reči: *implantat, unutrašnji fiksator, femur, metod konačnih elemenata,*
kompjuterska tomografija, planiranje operacija, bioinženjering