**FE MODEL OF METAPHYSEAL WEDGE FRACTURE FIXATION IN EXTRA-ARTICULAR PART OF DISTAL FEMUR**

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**Abstract.** Fractures of distal femur are infrequent but devastating complications. For their treatment it is necessary to have a stable internal fixation. To choose suitable type of implant for concrete fracture is important problem in orthopedic practice. This study tries to suggest, which of four implants is most suitable to treat metaphyseal-wedge fracture in extra-articular part of distal femur. The FE deformable leg model with implemented implant models was used for this purpose. The model was loaded by static force corresponding to maximal loading during walking. Distribution of implant von Misses stress was investigated.

1. INTRODUCTION

Biomechanical simulations used in area of traffic, army, sport, leisure time, also find their great assertions in medicine. This study is pointed to medical problem of treatment of extra-articular fracture of distal femur.

Generally, the extra-articular fractures of distal femur are divided into 3 types (Fig. 1).

![Fig. 1. Extra-articular fractures of distal femur according to [6] (A1 – simple, A2 – metaphyseal wedge, A3 – metaphyseal complex)](image)

There fractures occurring after total knee arthroplasty (TKA) implementation are infrequent (prevalence 0.3 to 2.5 %), but devastating complications. However their appearance rises as people age grows up and so the number of performed TKA increases. These fractures can occur during relatively low energy loading. The treatment of these
fractures is difficult, since it is influenced by bone quality, fracture type, surgical implant type and whole disposition of the patient. It is very difficult to involve all of these aspects into biomechanical model. Therefore there was paid attention specially to fracture A2, four types of implants were used and average 70 year old man femoral behavior was taken into account.

This study arose in cooperation with Faculty Hospital in Plzeň and tries to suggest, which of four implants is most suitable to treat A2 fracture. For this purpose FE leg model with implemented newly created implant models was used. The simulation and finite element analysis (FEA) were performed in PAM-CRASH™ solver [7]. Implant distributions of von Misses stresses during static loading representing the maximal loading during walking on plane were investigated.

2. METHODS

FE leg model with implemented TKA developed previously by [4, 5, 8] was used in this study. Model of femoral bone was divided into 3 segments to model A2 fracture. Consequently four types newly created implant models were integrated into femoral model (Fig. 2).

![Fig. 2. Investigated implants used to treat A2 fracture (dynamic condylar screw, condylar plate, distal femoral nail, non-contact bridging plate)](image)

2.1. Implant models

There were modeled two implants from anti-corrosive steel (condylar plate 95° (CP) and dynamic condylar screw (DCS)) and two implants from titanium alloy (distal femoral nail (DFN) and non-contact bridging plate (NCB)). The behavior of implants was supposed as elasto-plastic with isotropic hardening [15]. The elastic behavior was characterized by bulk modulus, K, and shear stress, G. Plastic hardening was described by yield stress, σy, and by tangent modulus, E_t (Table 1).
Table 1. Material parameters of implants

<table>
<thead>
<tr>
<th></th>
<th>$G$ [GPa]</th>
<th>$K$ [GPa]</th>
<th>$\sigma_y$ [GPa]</th>
<th>$E_t$ [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implants from anti-corrosive steel</td>
<td>79.23</td>
<td>171.67</td>
<td>0.30</td>
<td>0.62</td>
</tr>
<tr>
<td>Implants from titanium alloy</td>
<td>42.31</td>
<td>91.67</td>
<td>0.26</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Implants were fixated to the femoral bones by using two types of contacts offered by solver PAM-CRASH™ [7] a) sliding contact and b) tied contact. Sliding contact allows two parts to move with respect to each other. It was used to model the contact of plate and bone. Tied contact is characterized that the one part is positioned at certain distance from second one. It was used to capture the fixation of implant screws inside the bone. In this study there was also taken into account that the connection of some implants and screws is angle stable and for the other ones is no-angle stable. This situation was approximated by the use tied contact or the sliding contact.

2.2. Bone models

The leg model consists of femur, fibula, tibia, patella, four ligaments and two muscles. All the bones are modeled as deformable and they are divided into two parts. Compact part presented by set of shell elements and spongy part represented by set of solid elements. Material parameters of all leg segments were obtained from previous study [4, 5, 8]. There was paid attention to femoral model.

There was taken into account the isotropic behavior of femoral bone. The material parameters were obtained from [3]. The values of these parameters described the behavior of average femoral bone of 70 year old man. This age corresponds to the fact that average age of people with TKA is 70 years. The elastic behavior of compact femoral bone was characterized by Young modulus ($E = 16.3$ GPa) and by Poisson ratio ($\nu = 0.28$). The elastic behavior of spongy femoral bone was represented by shear modulus ($G = 23.1$ MPa) and by bulk modulus ($K = 50$ MPa). There was not taken into account the plasticity of bones, which decline with increasing age.

2.3. Completion of leg model

Because of the small time step, which was caused by the size of model elements, the scaling of mass and stiffness was used [7]. This possibility is offered by solver PAM-CRASH™. The scaling can only be used in case of static loading, i.e. dynamic loading representing the loading during walking could not be applied. As a consequence of the scaling use the inertial forces arose. These cause the vibration of the whole system. Hence it was necessary to apply the damping of inertial forces [7].

Damping for each node, which is proportional to added mass, is described by Eq. (1)

$$f_i = -m_i q_{crit} v_i$$

(1)

Where $f_i$ is internal damping force, $q_{crit}$ critical damping and $v_i$ nodal velocity vector. Critical damping for a 1 DOF system with circular frequency, $\omega$, is represented by Eq. (2)

$$q_{crit} = 2\omega = \frac{4\pi}{T}$$

(2)
In this study the computational time was 100 000 ms. Leg models were loaded from the top by static nodal force corresponding to maximal loading during walking on plane [9]. This force is 2.06 kN for average man, i.e. 75 kg. To simulate the situation of treading fully on one foot, the bottom parts of tibia and fibula were fixated.

To suggest, which of four implants is most suitable to treat A2 fracture, von Misses stress of individual implants was investigated. This comparative stress taking into account all stresses occurring in three directions is described by Eq. (3)

\[
\sigma = \sqrt{\sigma_{xx}^2 + \sigma_{yy}^2 + \sigma_{zz}^2 + \sigma_{xy}^2 + \sigma_{yz}^2 + \sigma_{xz}^2 - \sigma_{xx}\sigma_{yy} - \sigma_{yy}\sigma_{zz} - \sigma_{zz}\sigma_{xx}} \tag{3}
\]

Where \( \sigma_{xx}, \sigma_{yy}, \sigma_{zz} \) are normal stresses and \( \sigma_{xy}, \sigma_{yz}, \sigma_{xz} \) are shear stresses.

3. RESULTS

It was found that after 50 s all leg models already converged to the stable state. Therefore the von-Misses stress comparison of four implants at 50 s is visualized in Fig. 3.

3.1. Titanium distal femoral nail

The screw stresses increase minimally. The situation is different in case of nail, where the von Misses stress reaches 190 MPa at the thinning of nail. This fact can cause the rupture of nail during longer and bigger loading.

3.2. Non-contact bridging plate

The plate stress rises to 150 MPa around femoral fracture at concave part. The screw stresses reach 150 MPa at the low part of bone.
3.3. Dynamic compression screw

Von Misses stress is concentrated around screw holes, where it rises to 220 MPa. The other plate parts are without considerable stress changes. The noticeable changes of von Misses stress can be observed on the screws at the places, where screws leave the plate. The stress reaches 220 MPa. This fact causes the plastic deformation of screws and plate, which could lead to their rupture during bigger loading.

3.4. Condylar plate 95°

Screw von Misses stress reaches 200 MPa. This corresponds with fact that the plastic deformation of head screws can be observed. This is visible for most of the screws. This corresponds to the increase of plate hole stress to 230 MPa around mentioned screws and plate plastic deformation at this places.

4. CONCLUSION

This study compared the behaviour of two implants from anti-corrosive steel and the behaviour of two implants from titanium alloy. These implants are used for treatment of extra-articular fracture of distal femur in orthopaedic practice. There was paid attention to metaphyseal wedge fracture. Von Misses stress distributions of individual implants were investigated during loading by nodal force corresponding to maximal loading during walking on plane. It was found that the stress of non-contact bridging plate increased least from all implants. Moreover this implant has other advantages. It is less invasive for patients than other implants. Consequently, it is produced from titanium alloy, which is lighter than anti-corrosive steel. Finally as only one from the presented implants has angle stable fixation of screws in plate. This causes no movement of screws inside the bone after loading. In summary the NCB seems to be the most suitable implant and it could be used to treat metaphyseal-wedge fracture in extra-articular part of distal femur.

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REFERENCES

KONEČNĚ-PRVKOVÝ MODEL FIXACE NADKLOUBNÍ
KLÍNOVÉ ZLOMENINY DISTÁLNÍHO FEMURU

Summary. Nadklobové zlominy distálního femuru objevující se po implantaci
totální kolenní náhrady patří k nepříliš častým, ale závažným komplikacím
vedoucím k nutnosti dlouhodobé rehabilitace. I když jejich výskyt není častý, je jim
třeba věnovat pozornost. Jelikož s rostoucím věkem obyvatelstva roste počet
provedených totálních kolenních náhrad a tedy i pravděpodobnost vzniku tohoto
typu zlomény. Léčení těchto zlomín závisí na kvalitě kostí, dispozicích pacienta a typu implantátu určeného pro fixaci zlomény. Postihnout všechny
tyto aspekty v modelu je téměř nemožné. Proto v této studii byly brány v úvahu
vlastnosti femorální kosti pro implantací distálního podkolení 70-letého muže. Tento věk odpovídá
průměrnému věku, kdy je prováděna implantace kolenní náhrady. Pro
modelování fixace zlominy byl použit konečno-prvkový model nohy skládající
se z modelů kostí stehenní, lýtkové, holenní, špárek, kolenních vazů. Do tohoto
modelu byly implantovány čtyři nově vytvořené konečno-prvkové modely
implantátů. Tyto implantáty jsou v ortopedické praxi běžně využívané pro fixaci
zlomín distálního femuru. Celý model kostí s různými typy implantátů byl
staticky zatížen silou odpovídající maximální sile působící na femorální kost
během chůze po rovinaté podložce. Vhodnost implantátu byla usuzována
z vyšetřování distribuce napětí von Misses. Bylo zjištěno, že napětí von Misses
implantátu non-contact bridging plate je nejmenší v porovnání s dalšími třemi
implantáty. Navíc tento implantát má několik dalších výhod. Je lehčí než dlahy
z nerez oceli. Jeho implantace je šetrná k pacientovi. Navíc má úhlově stabilní
fixaci šroubů uvnitř dlahy, což zamezuje pohybu šroubů uvnitř kosti po zatížení.
Tedy implantát non-contact bridging plate se zdá nejvídějnějším pro léčení
nadklobové klinové zlominy distálního femuru.