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Numerical Analysis of Standard and Modified Osteosynthesis in Long Bone Fractures Treatment

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A B S T R A C T

The fundamental problem in osteoporotic fracture treatment is significant decrease in bone mass and bone tissue density resulting in decreased firmness and elasticity of osteoporotic bone. Application of standard implants and standard surgical techniques in osteoporotic bone fracture treatment makes it almost impossible to achieve stable osteosynthesis sufficient for early mobility, verticalization and load. Taking into account the form and the size of the contact surface as well as distribution of forces between the osteosynthetic materials and the bone tissue numerical analysis showed advantages of modified osteosynthesis with bone cement filling in the screw bed. The applied numerical model consisted of three sub-models: 3D model from solid elements, 3D cross section of the contact between the plate and the bone and the part of 3D cross section of the screw head and body. We have reached the conclusion that modified osteosynthesis with bone cement resulted in weaker strain in the part of the plate above the fracture fissure, more even strain on the screws, plate and bone, more even strain distribution along all the screws' bodies, significantly greater strain in the part of the screw head opposite to the fracture fissure, firm connection of the screw head and neck and the plate hole with the whole plate and more even bone strain around the screw.

Key words: *modified ostheosynthesis, numerical analysis, osteoporosis*

Introduction

The fundamental problem in osteoporotic fracture treatment is significant decrease in bone mass and bone tissue density and thus in decreased firmness and elasticity of osteoporotic bone. Osteoporotic patients' fractures are treated with standard surgical techniques of osteosynthesis and standard implants, which means in the same way as in patients who do not have osteoporosis. In such treatment standard screws have considerably lesser contact with the bone due to changed bone structure, which results in significantly weaker strain on the contact surface between the screw and the osteoporotic bone (strain = force / contact surface). Application of standard implants and standard surgical techniques in osteoporotic bone fracture treatment makes it almost impossible to achieve stable osteosynthesis sufficient for early mobility, verticalization and load[1].

Laws of biomechanics clearly indicate that to obtain stable osteosynthesis in osteoporotic patients it is necessary to increase the contact surface between the metal implants and the bone in order to obtain greatest possible local strain[1–5]. Local strain rate needs to be sufficient to prevent development of unstable osteosynthesis, which occurs as a result of microfractures and loosening of the screw and osteosynthetic material[6–10]. One of possible solutions is application of standard implants and screws whereby the screw bed in the bone, but not on the fracture point, is filled with bone cement[11,12]. Bone cement is

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additional stabilizing factor that fills in the hollows between the metal implants and the osteoporotic bone. After completed polymerization it significantly increases local strain rate and thus osteosynthesis firmness, which ensures stability of fractured bone fragments[13,14].

Due to fracture healing process osteosynthetic material is under great strain. The forces acting on ostaosynthetic material are responsible for proper fracture healing and later proper leg biomechanics. The forces act not only on osteosynthetic material but also on the fractured bone and thus participate in its healing.

Different bone healing stages and later bone development are under influence of the bone environment. Action of mechanical forces can significantly change calus development[12].

Action of forces should be adjusted to optimal bone healing. If a force is too great, it would cause lossening of osteosynthetic material, and if it is too weak it would not result in desired bone healing.

Adapters built into ostaosynthetic material monitor the implant condition and calus development as a result of action of forces on the bone and the implant itself. Thus the force strength can be adjusted to enable proper bone healing and to avoid implant decay or repeated fracture due to action of a too great force.

One of the methods applied in long bones fractures treatment in osteoporotic patients is increase of the contact surface between the implant and the osteoporotic bone by injection of bone cement (methyl-metacrylat, Palakos) into the screw bed. Taking into account that standard osteosynthesis is still in use, our intention was to use numerical analysis to show the size and form of contact surfaces as well as distribution of forces that appear when there is expected strain in the fracture area and contact of osteosynthetic material with the bone tissue.

Materials and Methods

Transferred from the mechanical model onto the research model, actions in the supports A, B and D correspond to the contact between the screw head and the plate in the standard osteosynthesis, as well as to a spherical joint. Contact connection (spherical joint) of the screw head and the plate is achieved by a circular connection of the screw head and the edge of the plate hole, and rotational firmness of this connection depends on the value of the screw tightening force F_V and coefficient of friction (μ) of metal against metal. Since the tightening force of the screw F_V is limited by the firmness of the cortical bone which is ten times lesser than the firmness of the metal (implant), and coefficient of friction of metal against metal is extremely low, the friction is not a sufficient mechanism to achieve firmness. It is therefore necessary to achieve fixing by the form of material. In the procedure applied in this research it is achieved by bone cement which completely fills in the space along the screw neck and the plate hole. In this way the plate and the screw act as one hard body, which results in significantly more evenly distributed strain[15].

To analyze objectively specific characteristics of the standard and modified osteosynthesis of femoral fracture we have designed a numerical model consisting of three parts:

a) »3D model from solid elements« of the standard femoral osteosynthesis with the plate and screws and the model improved with the bone cement, consisting of the proximal and distal bone parts B_P and B_D, plate P and the bone cement – Polymethylmetacrylat (PMMA) between the plate and the bone shown at the ends of the plate

b) 3D cross section of the contact between the plate and the bone, where axial load is transmitted when tightening the screw and in torsional bone loading

c) Part of 3D cross section of the screw head G, circular surface CS_1 of the plate and head contact, circular surface CS_2 of the plate and head that do not transmit significant contact load (connective tissue) to this surface after osteosynthesis and finally screw threading ST of the screw in the bone.

Practical application of finite element method requires knowledge of different computer programmes:

Material constants (Young's modulus and Poisson coefficient) of the used materials were taken from the biomechanics textbook: E for bone = 20 GPa, E for plate and screws = 200 GPa, E for bone cement = 3.1 GPa, while Poisson coefficient 0.4 was used for all materials[3]. A computer program package (16) CATIA V5 R13, – CAD (Computer Aided Design) from the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, was used in the research of standard and modified osteosynthesis resistance to mechanical influence. In this program package the following procedures were carried out:

a) 3D modelling of individual parts, their assembling into a unit at common contact surfaces and edges which have to match geometrically, e.g. the surface of the thread spiral point in the bone matches the same in the cortical screw. Dimensions of the cortical AO screw were taken from the international standard ISO 5835[17] according to which the presented 3D »solid model« was designed as well as its negative form – threaded hole in the bone.

b) Mesh generation (meshing) is the practice of generating a 3D mesh for a body volume done by a computer, whereby the computer is given a type of mesh (e.g. tetrahedral), size and density of the local mesh (LM) in areas where greater strain is expected (for example 0.2 mm in the area of the screw neck and the plate hole). It is important to match the size of the mesh to corresponding contact surfaces and ensure matching of the meshes on the same surfaces. The mesh may be displayed or hidden as necessary.

c) Defining constraints is a procedure that determines the load (axial force F_{ax} and torsion moment M) and possible motions of single points and/or connections on contacts of the elements or edges (e.g. sliding connection, rotation around a certain axis and similar) determined on the basis of analytical problem analysis. In both cases (with and without bone cement) the bone and screw connection is in eight places firm, immovable connection (FC), while the connections between the linear plate and bone contacts are sliding connections (SC). The case with the bone cement has additional firm connections of the circular surfaces CS_2 of the screw neck, bone cement and plate holes. In both cases there are sliding connections with pre-load (SCpL) between the bone fragments and circular surfaces CS_1 of the screw heads and plate holes.

The program ABAQUS was used as solver[18], since it is one of high quality programs for numerical analysis of solid and elastic materials. Calculations were done using great number of 3D finite elements: 630,417 tetrahedars in standard osteosynthesis and 809,222 tetrahedars in modified osteosynthesis.

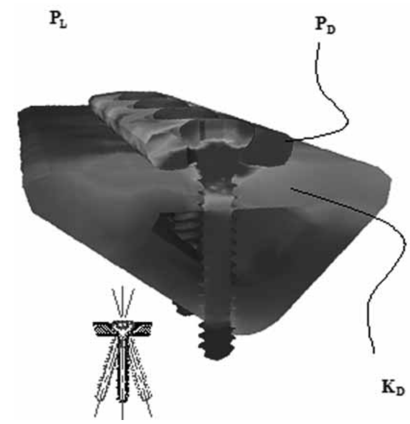

Fig. 1. Numerical model of cross sections of macerated cadaveric tibia in standard osteosynthesis.

Results

Figure 1 shows cross sections of the computer model of macerated cadaveric tibial body, where modified osteosynthesis with bone cement is shown in 3D cross section through the second screw in the distal fragment (Figure 2) and standard osteosynthesis without bone cement is shown in 3D cross section of the first screw in the proximal fragment (Figure 1). The difference in distribution and intensity of the strain between modified and standard osteosynthesis is evident in all cross sections:

1. Significant difference in distribution of the plate strain on its right and left side ($P_{R,}$ P_L). In modified osteosynthesis the screw head and neck as well as the plate hole were firmly connected to the whole plate by bone cement. Thus, the screws and the plate made a firm compact body so that torsion load was transmitted to both sides of the plate. In standard osteosynthesis there was no bone cement and no firm connection between the screw and the plate and thus the torsion load was mostly transmitted to one side of the plate (the right side of the plate in the proximal fragment, P_R). Torsion load was transmitted to the opposite side in the distal fragment with the same values and distribution.

2. Noticeable difference in distribution and intensity of the bone strain on the right (B_R) and the left side of the bone in its cross section was identical to distribution and intensity of the implant strain. In modified osteosynthesis with bone cement the bone strain around the screw was more evenly distributed and confirmed better transmittion of the plate firmness to the surrounding bone. Bone cement acted as additional mechanical element in creation of multi-directional three-dimensional firmness, which ensured significantly better mechanical unity of bone-screw-plate system and thus far better compatibility of elements used in fracture treatment.

The strain distribution was not even in numerical model of the standard osteosynthesis of macerated cadaveric tibial fracture (Figure 3). The highest strain concentration occurred in the middle part of the plate above the fracture fissure and in the part of the bone cortex below it. Torsion moment caused edge strain only on one side of the plate adjacent to the fracture fissure. This strain was the result of torsion force applied on numerical model which led to additional strain caused by pressure between the plate edge and the bone. The strain in the screw heads was insignificant.

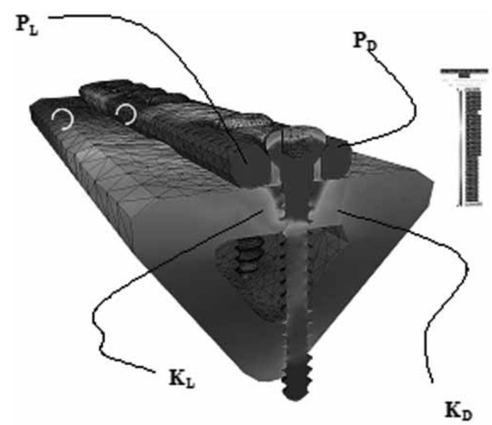

Fig. 2. Numerical model of cross sections of macerated cadaveric tibia in modified osteosynthesis.

The strain in the plate, screws and the bone under the plate was noticeably more evenly distributed in modified osteosynthesis with bone cement (Figure 4). The strain in the middle part of the plate above the fracture fissure and in the cortex below it was much less intense than in standard osteosynthesis. The plate edges received weaker strain, which was evenly distributed over a longer segment along the both sides of the plate. Also, there was strain in all screw heads in proximal and distal fragments.

In standard osteosynthesis of macerated cadaveric tibial fracture the greatest strain occurred in the small part of the screw neck immediately below the head, while in screw heads the strain almost did not occur (Figure 5). The lower part of the plate was also subjected to great strain, but only in the part above the fracture fissure and in the first two screws adjacent to the fracture fissure in

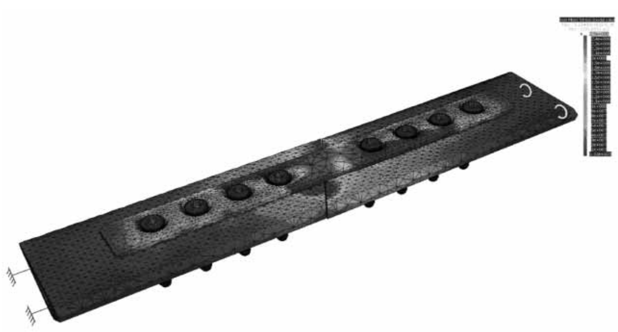

Fig. 3. Numerical model of contact surface in standard osteosynthesis.

Fig. 4. Numerical model of contact surface in modified osteosynthesis.

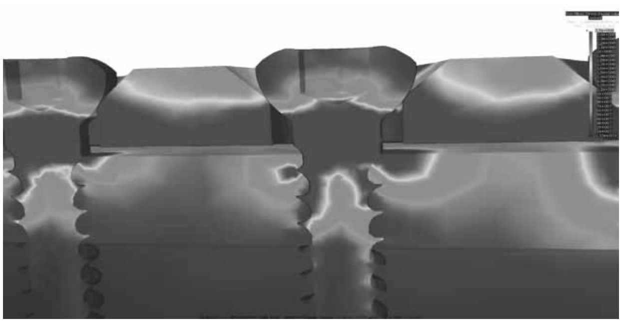

Fig. 5. Numerical model of the small part of the screw neck immediately below the head in standard osteosynthesis.

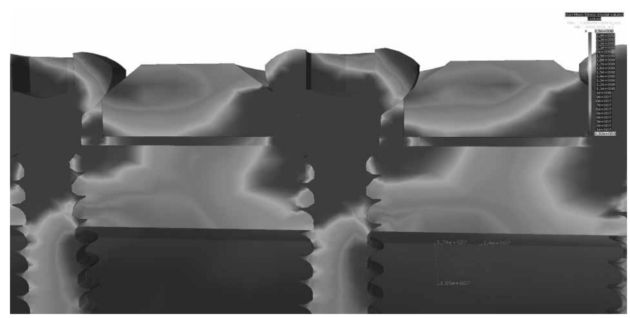

Fig. 6. Numerical model of the small part of the screw neck immediately below the head in modified osteosynthesis.

the proximal and distal fragment. In the part of the screw body that was placed in the outer cortex the strain was weaker and not evenly distributed and it was transmitted to the corresponding cortex only in a narrow part adjacent to the plate and screw body surrounding area.

The space between the plate hole and the cortex in modified osteosynthesis was filled in with bone cement (Figure 6), which ensured the firm connection between the screw head, plate and the cortex below the plate. This firm system resulted in even strain distribution, which occurred in screw heads and necks as well as in the cortex around the screw body.

Disscussion and Conclusion

It is a well-known fact that long bones fractures occur more frequently in osteoporotic patients. Such fractures most frequently occur in vertebrae and in long bones and have tendency for prolonged healing due to bone mass decrease and depletion of calcium and bone protein. To shorten the time needed for rehabilitation and to achieve better anatomical relations and patients' verticalization[19] it is recommendable to perform surgery that includes osteosynthesis of a fractured osteoporotic bone. Prior to this procedure an evaluation of the mineral structure of the osteoporotic bone should be made as well as modelling of the implant that will be used in fracture treatment[20]. The choice of method and materials needed for osteosynthesis is a problem. Throughout the history of osteosynthesis since 1895 various methods were used. At present it has become a priority to find osteosynthetic material that will enable axial growth of the bone with micromovements through fracture fissure based on clinical success achieved by Ilizarov, who showed the significance of axial movement of dynamic load[21]. We are currently using plates and screws that will cause the least possible disturbance of the surrounding soft tissue and the periosteum simultaneously avoiding disturbance in bone vascularization[22]. There are different methods at disposal. The method of intramedullary fixation combines best characteristics of osteosynthetic materials such as intramedullary nails and the use of Schanz screws[23], LC-DCP (limited contact dynamic compression plate) plates that evolved from DCP plates (dynamic compression plate) which are made in trapezoid form that enables calus development and minimizes vascularization damage, may be shaped and are made of titanium alloys[24]. Also to be considered are LISS (less invasive stabilising system) acts as internal fixator, but it is actually osteosynthetic plate which is fixed to the bone with screws, as well as introduction of self-locking screws that, unlike other screws, may have the bed in just one cortex[25,26].

We have reached the conclusion that modified osteosynthesis with bone cement resulted in weaker strain in the part of the plate above the fracture fissure, more even strain on the screws, plate and bone, more even strain distribution along all the screws' bodies, significantly greater strain in the part of the screw head opposite to the fracture fissure, firm connection of the screw head and neck and the plate hole with the whole plate and more even bone strain around the screw.

R E F E R E N C E S

1. HANČEVIĆ J, NIKOLIĆ V, HUDEC M, HUDEC F, BANOVIĆ B, Biomehanika stopala (Medicinska naklada, Zagreb, 1977). — 2. NIKOLIĆ V, HUDEC M, Principi i elementi biomehanike (Školska knjiga, Zagreb, 1988). — 3. PANJABI M.M, WHITE AA, Biomechanics in the Musculosceletal System (Churchill Livingstone, Philadelphia, 2001). — 4. PAUWELS F, Beilgeheft Z Orthop Chir, (1935) 63. — 5. RISTANOVIĆ D, SIMONOVIĆ J, VUKOVIĆ J, RADOVANOVIĆ R, Biofizika II prerađeno i dopunjeno izdanje (Medicinska knjiga, Beograd-Zagreb 1984). — 6. HANČEVIĆ J, HUDEC M, HUDEC F, NIKOLIĆ V, BANOVIĆ B, Biomehanički odnosi alenteze i kostanih fragmenata pri unutarnjim osteosintezama. In: Proceedings (Zbornik radova JUREMA, Zagreb, 1979). — 7. HANČEVIĆ J, NIKOLIĆ V, DAVILA S, Primjena biomehanike u traumatologiji. In: Proceedings (15. Kongres kirurga Jugoslavije, Ljubljana, 1980). — 8. HANČEVIĆ J, NIKOLIĆ V, DAVILA S, Primjena biomehanike u traumatologiji. In: Proceedings (15. Kongres traumatologa Jugoslavije, Ljubljana, 1980). — 9. HANČEVIĆ J, NIKOLIĆ V, HUDEC M, KOKOT V, PETRIČEVIĆ A, JELIĆ I, Acta Chir Iug, 24 (1977) 549. — 10. HERTEL P, BERNARD M, MOAZAMI-GOUDARZI Y, Orthopade, 6 (1991) 341. — 11. GOODMAN SB, BANER TW, CARTER D, Clin Orthop, 348 (1998) 42. — 12. HANČEVIĆ J, NIKOLIĆ V, HUDEC M, VUKIČEVIĆ S, VINTER S, Acta chir Iug, 24 (1977) 225. — 13. KRAMER A, ANGST M, GASSER B, GANZ R, Z Orthop Ihre Grenzgeb, 138(5) (2000) 464. — 14. McKOY BE, AN YH, J Biomed Mater Res, 53 (2000) 216. — 15. BEER FP, JOHNSTON ER, Mechanics of Materials, Second Edition (Mc Graw – Hill Inc, New York, 1992). — 16. REMBOLD RW, Konstruktion in Übungen und Beispielen (Carl Hanser Verlag, München Wien, 2003). — 17. INTERNATIONAL STANDARD ISO 5835:1991(E), Implants for surgery – Metal bone screws with hexagonal drive connection, spherical under-surface of head, asymetrical thread – Dimensions. — 18. ABAQUS / CAE User's Manual; Hibbitt, Karlson & Sorensen Inc, 2004. — 19. HOOPER GJ, KEDDELL RG, PENNY ID, J Bone Join Surg Br, 73B (1991) 83. — 20. STROMSOE K, Inj, 35 (2004) 107. — 21. UNTHOFF HK, POITRAS P, BACKMAN DS, J Orthop Sci, 11 (2006) 118. — 22. BROOS PLO, SERMON A, Acta Chir Belg, 104 (2004) 396. — 23. KIM KC, LEE JK, HWANG DS, YANG JY, KIM YM, Ortho, 30 (2007) 906. — 24. KLAUE K, FENGELS I, PERREN SM, Inj, Suppl 2:S-B (2000) 51. — 25. PERREN SM, J Bone Joint Surg Br, 84B (2002) 1093. — 26. MULLER ME, ALLGOWER M, SCHNEIDER R, WILLENEGGER H, Manual of internal fixation. Tehniques recommended by the AO-ASIF group (Springer-Verlag, Berlin Heidelberg New York Tokyo, 1991).

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NUMERIČKA ANALIZA STANDARDNE I MODOFICIRANE OSTEOSINTEZE U LIJEČENJU PRIJELOMA DUGIH KOSTIJU

S A Ž E T A K

Temeljni problem u zbinjavanju osteoporotičnog loma predstavlja značajno smanjenje koštane mase i gustoće koštanog tkiva, a samim tim čvrstoće i elastičnosti osteoporotične kosti. Primjenjujući standardne implantate i standardnu operacijsku tehniku u zbrinjavanju loma osteoporotične kosti, gotovo je nemoguće ostvariti stabilnu osteosintezu dostatnu za ranu mobilizaciju, vertikalizaciju i opterećenje. Obzirom na oblik i veličinu kontektne površine kao i razdiobu sila izmedju osteosintetskog materijala i koštanog tkiva u radu se numeričkom analizom pokazuje prednost modificirane osteosinteze s ubacivanjem cementa u ležište vijka. Navedeni se numerički model sastojao od tri podmodela: 3D modela iz solid elemenata, 3D presjeka kontakta izmedju pločice i kosti te detalja 3D presjeka glavice i trupa vijka. Zaključili smo da modificirana osteosinteze s koštanim cementom pokazuje manje naprezanje u dijelu pločice iznad lomne pukotine, ravnomjernije naprezanje vijaka, pločice i kosti, ravnomjerniju raspodjelu naprezanja uzduž tijela svih vijaka, značajno veća naprezanja u dijelu glavice vijka nasuprot lomnoj pukotini, glavica, vrat vijka i otvor pločice čvrsto su povezani s cijelom pločicom, ravnomjernija naprezanja kosti oko vijka.