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COMPUTER REPRESENTATION OF OSTEOSYNTHESIS STABILITY IN LOCKING PLATES USED FOR THE TREATMENT OF OSTEOPOROTIC PROXIMAL HUMERUS FRACTURES

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SUMMARY

Background: *Proximal humerus fractures are represented as 4-5% of all fractures, with incidence notably growing with age. Since surgical internal fixation in treatment of proximal humeral fractures is used, fractures of osteoporotic bone and choice of plate for their osteosynthesis represent particular problem. The aim of the study was to test two locking plates: Philos plate with locking screws with determinated direction, and Arthrex plate with poliaxial locking screws, using the finite element method.*

Subjects and methods: *This study used version 6.10 of Abaqus FEA software package for simulation and fine element analysis of Philos and Artrex plates attached to the osteotomy models of proximal humerus with fracture gap at 0°, 10° and 20° in four types of static load: abduction, adduction, axial compression and flexion. Simulation results of loads in abduction, adduction, axial loads and flexion, were described with the total bone displacement (U) and maximum bone displacement in the fracture gap (U_f).*

Results: *When examining the Philos plate in axial load on the bone with fracture gap angle from 0°, 10° and 20° no significant differences between the results for the displacements were observed. Therefore, results for other loads are related to total displacements of the bone only at the angle of 0°. Given that the results of the total bone displacement and maximum bone displacement in the fracture gap with Artrex plate were mostly higher, for comparison with the results of bone displacement in Philos plate it was taken that total bone displacement and maximum displacement in the fracture gap in Artrex plate represent 100% of the total displacement. Philos plate showed 60.71% for abduction, 76.07% for adduction, 102.24% for axial loads and 79.59% for flexion of total bone displacement in Artrex plate, and 60.48% for abduction, 76.07% for adduction, 96.05% for axial load and 79.96% for flexion of maximum displacement in the fracture gap in Artrex plate.*

Conclusions*: Osteosynthesis for osteoporotic fractures of proximal humerus with Philos plate in computer simulation proved to be more stable than with Arthrex plate.*

Key words: *computer simulation - finite element method - proximal humerus fracture - osteoporotic fracture - locking compression plate*

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INTRODUCTION

Proximal humerus fractures are represented as 4-5% of all fractures, with incidence notably increased in women, growing with age (Kristiansen 1988). In older women these fractures are twice as frequent than in men. Their incidence grows with patients age (Horak & Nilsson 1975). 87% of all osteoporotic fractures occurs after fall in the level. The more osteoporosis is expressed, the fractures are more complex (Court-Brown et al. 2001).

In last fifty years, since surgical internal fixation in treatment of fractures is used, fractures in osteoporotic bone represent particular problem (Struhl et al. 1990). Plate - screw connection is realized by circular connection of screw head and the edge of the plate's hole. Rotational strength of the connection depends on the size of the screw's tightening force and metal on metal friction factor (Mckoy & An 2000). Since the tightening force of the screw is limited by ten times lower firmness of cortical bone than the metal, and a factor of metal on metal friction is extremely small, in this case, the friction represents securing mechanism which is insufficient. This combination results in loosening the bone – implant connection. Ultimately screw extraction, plate mobility and loss of stability at the fracture site occurs (Flahiff et al. 1995, Chen et al. 2009). When bone is osteoporotic, the cortex is thinned, cancellous bone is built of gracile beams and bone tissue is brittle due to reduced density and changes in trabecular structure. Osteoporotic bone is less susceptible to deformation, and has a lower module of elasticity. Because of the above bone-plate connection is unstable, and the screw in the osteoporotic bone doesn't have safe and permanently stable stronghold (Jensen et al. 1990, Drew & Allcock 2002, King & Cebon 1993). Local contact between the screw and the bone is small, and soon after the osteosynthesis bone - osteosynthetic material connection begins to loosen with all the negative consequences in post-operative treatment (Schandelmaier et al. 2001, Frigg 2003, Gautier & Sommer 2003). Well developed and firm cortex and well developed and dense cancellous bone allows less strain on the screw – bone connection, thereby ensuring stable stronghold for screw and high pressure between the bone fragments, reducing possibility for osteolysis and microfracture development on the contact surface (Wenzl 2004, Miller & Goswami 2007). The laws of biomechanics suggest that for a stable osteosynthesis of osteoporotic bone increasing the contact surface of metallic implants and bone or increasing the stability of the connection screw - plate - bone is necessary. Increasing the contact area can be achieved through applying a modified osteosynthesis by placing bone cement in screw location. In this way, after poly-merization, bone cement significantly increases the amount of bone contact and rigidity of osteosynthesis enabling inaction of bone fragments. AO school that kind of osteosynthesis called composite osteosynthesis. There is also another option and that is to increase the stability of the screw - plate - bone connection (Šišljagić et al. 2009, 2010).

In addition to these features, increasing knowledge about the healing of fractures, also increased the awareness of importance to preserve local biological conditions, especially the vitality of the bone, in order to preserve the factors that affect the healing of fractures in surgical procedures (Šišljagić et al. 2010).

In previous studies, locking compression plate (LCP) was compared with many standard plates regarding bending and torsion tests. Flexural strength and flexural rigidity of LCP is not significantly different from limi-ted contact-dinamic compression plates (LCDCP) or dinamic compression plates (DCP) regarding tests of the plate itself and tests on the model of artificial bone with osteotomy. Torsion tests also found that there was no significant differences in the strength or stiffness bet-ween the three kinds of plates. Studies comparing the mechanical behavior during fixation with LCP that semi-silhouettes the bone and LCDCP that anatomicaly outlines the bone revealed no difference in structural stiffness and no implant fracture even after 63000 cycles. The methodology of these studies was based on the strength between the bone and the plate, rather than on the interaction between the plate, screw and bone. Taking into account the load to fracture site in bending and torsion, LCP can be used in a similar way as the DCP and LCDCP in clinical practice (Kowaleski 2012).

In this study, we used computer simulations of two locking plates, one of the plates was with locking screws with determinated direction (Philos, Synthes, Switzerland), and the other with poliaxial locking screws (Humeral SuturePlate, Arthrex, USA). The goal was to test these two plates using finite element analysis and to determine and compare osteosynthesis stability for these two plates. This study used a version of Abaqus 6.10 for simulation of osteosynthetic plates Philos and Artrex attached to the proximal humerus in four types of static load: abduction, adduction, axial compression and flexion.

SUBJECTS AND METHODS

For the purposes of this simulation boundary conditions between the screws and bone, and between plates and screws were set. In that way the plate and screws, and screws and bone were associated with hard links (tie). The bone was fixed in it's ends, the head of the humerus and the distal part of the humerus body, which corresponds to real conditions - fixation of the humerus at shoulder and elbow. Between the plates and bone, the models were without contact to make locking plates benefits more evident. Locking plate does not need to be in contact with the bone (periosteum). That is desirable because it ensures better vascularization of bone fragments, which is requirement for faster bone healing and fewer complications. Osteotomy was made in the same place in length of 10 mm in all models. Fracture gap was located at 0°, 10° and 20° (Figure 1).

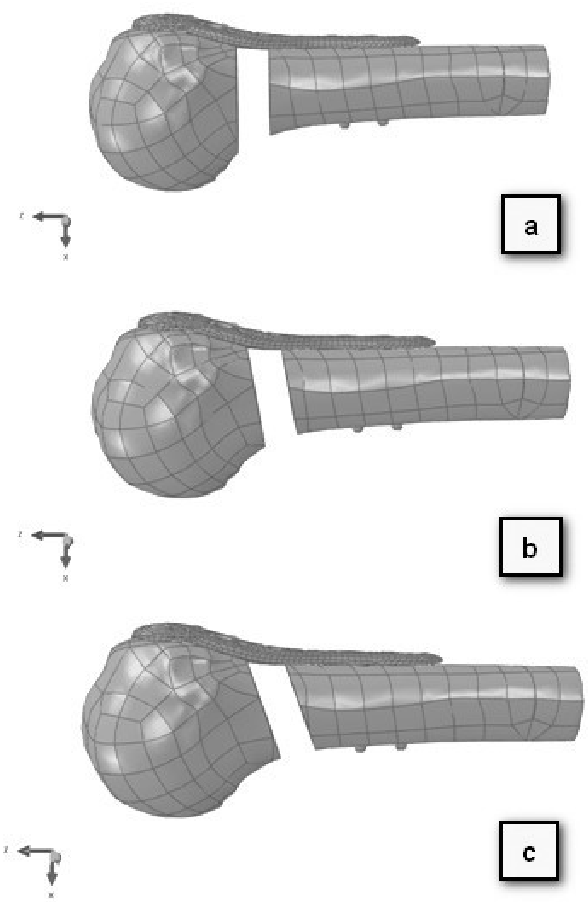

Figure 1. a) Fracture gap at 0° osteotomy, b) Fracture gap at 10° osteotomy, c) Fracture gap at 20° osteotomy

All plate constructs were meshed using ten node quadratic tetrahedral elements C3D10. Finite element mesh consisted of 1.1 to 1.2 million elements, de-pending on the type of the plate (Philos and Artrex) and the number of screws (Figure 2). The element size was chosen based on a mesh convergence analysis of dis-placements by using a model with Philos plate under axial load. All material properties were assumed homogeneous, isotropic and linear.

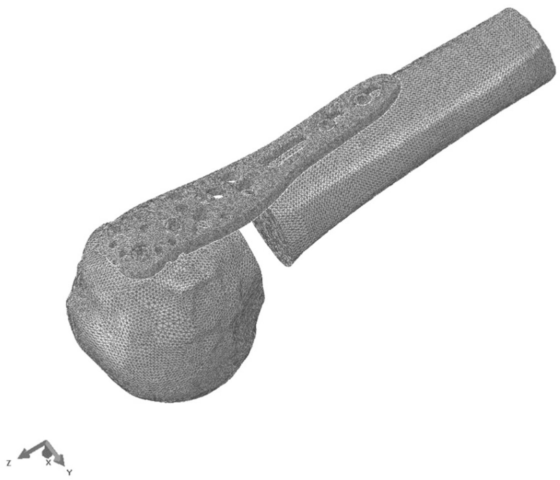

Figure 2. Finite element mesh in proximal humerus with Philos plate

Material properties, modulus of elasticity (E) and Poisson ratio (υ), are the same in all models:

- Bone: E=13.7 GPa, υ=0.3;
- Titanium: E=120 GPa, υ=0.3.

Forces on the bone are placed on the way to transfer muscle forces acting at a specific load more realistically. Directions and insertion forces are shown in Figure 3. During the simulation the models were loaded with 100 N applied across an appropriate surface of the proximal humerus. This force was chosen because bone, plates and screws need to be in the elastic range, respectively, plastic deformation must not appear in order to accomplish better bone healing. Computer simulations with the fracture gap at an angle of 0°, 10° and 20° were conducted for the Philos plate model with an axial load. As in all three cases the displacements were the same, for other loads and models with Artrex plate calculations were carried out only with the osteotomy angle 0°.

RESULTS

When examining the Philos plate after axial load on the bone with fracture gap angle β from 0°, 10° and 20° no significant differences between the results for the displacements were observed (Table 1). From that we can make conclusion that the angle of the fracture gap on the bone does not affect the overall displacement of the model. For this reason, the results for other loads are related to total displacements of the bone only at the angle of 0°.

Table 1. Axial load of bone with philos plate at different angles of fracture gaps

Fracture gap angle β	Total bone displacement U [mm]
0°	1.534
10°	1.534
20°	1.534

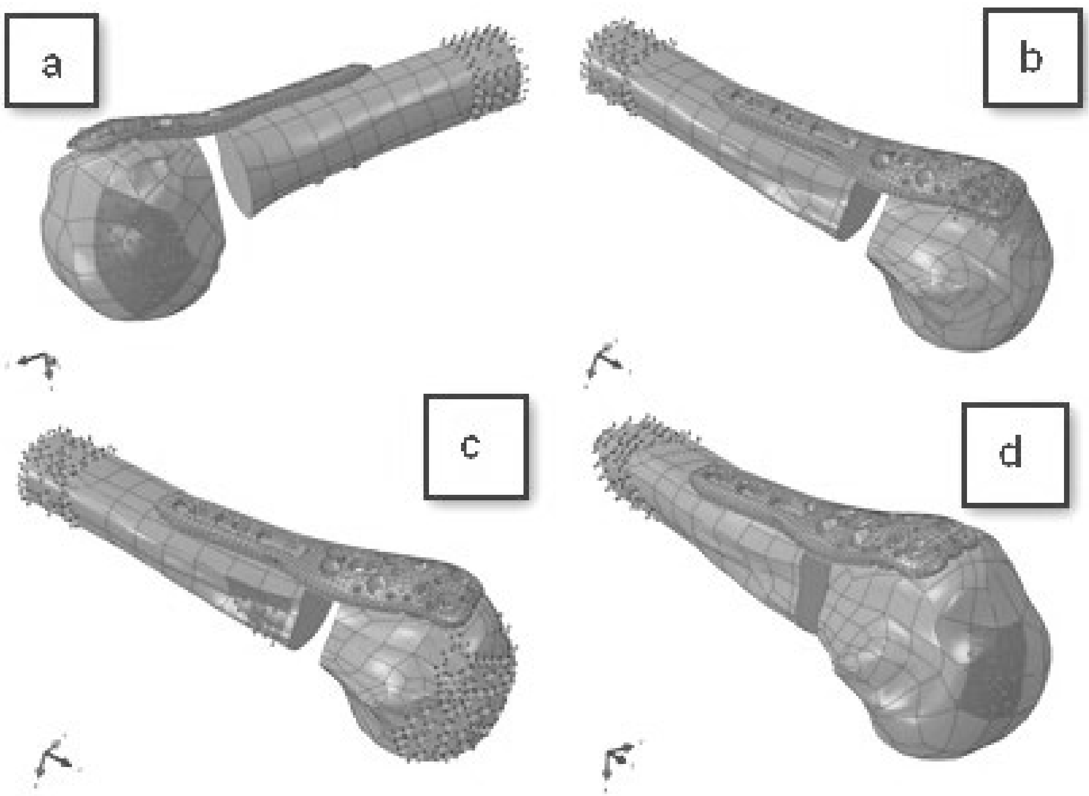

Figure 3. Loading conditions of models during: a) abduction, b) adduction, c) axial compression, d) flexion

Simulation results of loads in abduction, adduction, axial loads and flexion, with bone fracture gap at 0°, are described with the total bone displacement (*U*) and maximum bone displacement in the fracture gap (U_f), and are presented in Table 2. For example locations and values of the maximum bone displacement in the fracture gap for both plates under flexion are shown in Figure 4. Figure 5 shows the difference between the total bone displacements, and the difference between the maximum bone displacements in the fracture gap for the Philos and Artrex plate, for four types of loads. Given that the results of the total bone displacement and maximum bone displacement in the fracture gap with Artrex plate are mostly higher, for comparison with the results of bone displacement in Philos plate it will be taken that total bone displacement and maximum displacement in the fracture gap in Artrex plate are representing 100% of the total displacement (Figure 6).

Table 2. Results of the total bone displacement and maximum bone displacement on the proximal edge of the fracture gap

Type of load	Total bone displacement *U* [mm]		Maximum bone displacement in the fracture gap U_f [mm]	
	Philos	Artrex	Philos	Artrex
Abduction	4.407	7.259	2.479	4.099
Adduction	$4.567 x 10^{-2}$	$6.004 x 10^{-2}$	$4.567 x 10^{-2}$	$6.004 x 10^{-2}$
Axial load	1.534	1.500	$8.780 x 10^{-1}$	$9.141 x 10^{-1}$
Flexion	2.405	3.022	1.619	2.024

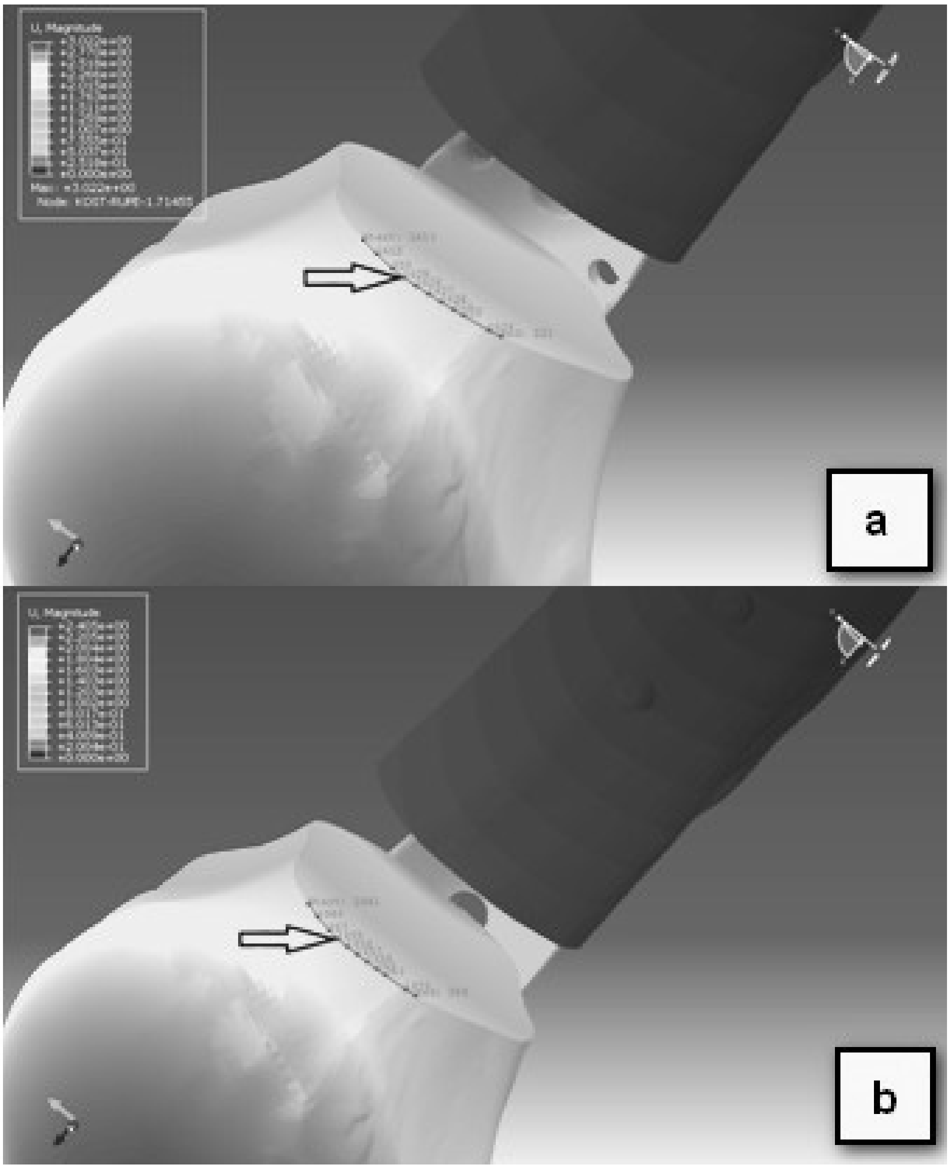

Figure 4. a) Maximum bone displacement on the proximal edge of the fracture gap for Artrex plate under flexion, b) Maximum bone displacement on the proximal edge of the fracture gap for Philos plate under flexion

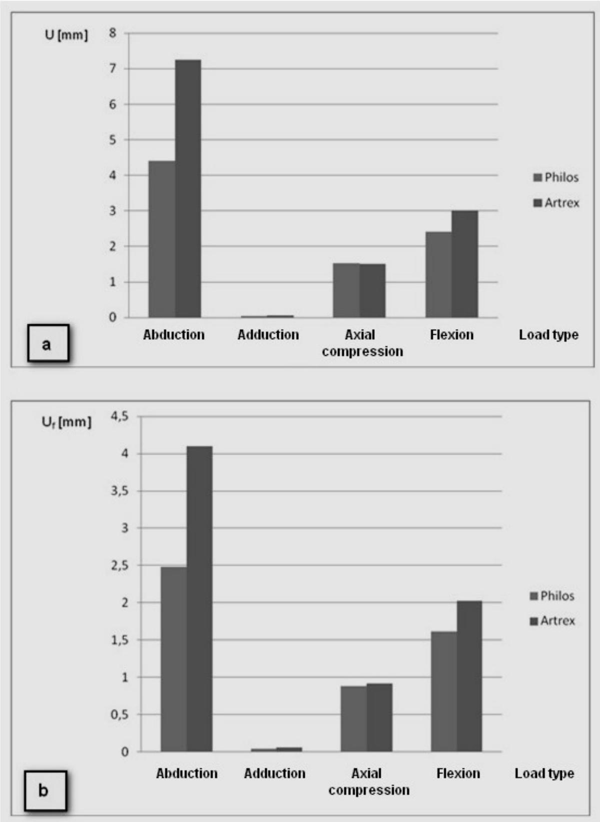

Figure 5. a) Maximum displacements on the proximal end of the models, b) Maximum displacements on the proximal edge of the fracture gap

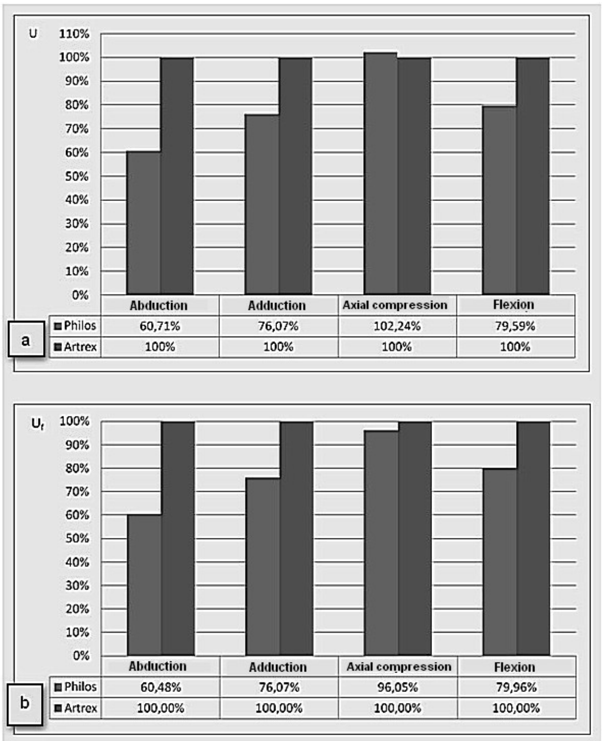

Figure 6. a) Comparison of the results for the total bone displacement(U), b) Comparison of the results for the maximum bone displacement on he edge of the fracture gap (U_f)

DISCUSSION

Osteoporotic fractures are becoming more common in the overall population, particularly among the elderly. Healing process in osteoporotic bone is very slow, therefore treatment of such fractures should be taken with much care, keeping in mind high number of pseudoarthrosis and non-unions requiring new operations which include demanding, time-consuming and expensive treatment. There are many surgical modalities for treatment of this kind of injuries. Locking plates proved to be one of the best solutions for treatment of proximal humerus fractures in osteoporotic bone.

Following the development of new technologies, particulary informatics a new approach for implant testing emerged. This new approach emphasizing computer simulations and fine element analysis is useful in early testing of newly designed implants for their stability prior to their biomechanical and clinical studies.

CONCLUSION

In this study the stability of two LCP plate construct was analysed using the finite element method. The computer simulations were performed using the finite element software package Abaqus 6.10-1, on bone models with two types of locking plates, Philos and Artrex, under static loads of abduction, adduction, flexion and axial load. In simulations the total bone displacements and maximum bone displacements in the fracture gap were measured. Results showed that the osteosynthesis with Philos plate is more stable.

Also, in our everyday clinical practice, Philos locking plate proved to be more practical and technically easier to use during surgery.

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Conflict of interest : None to declare.

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